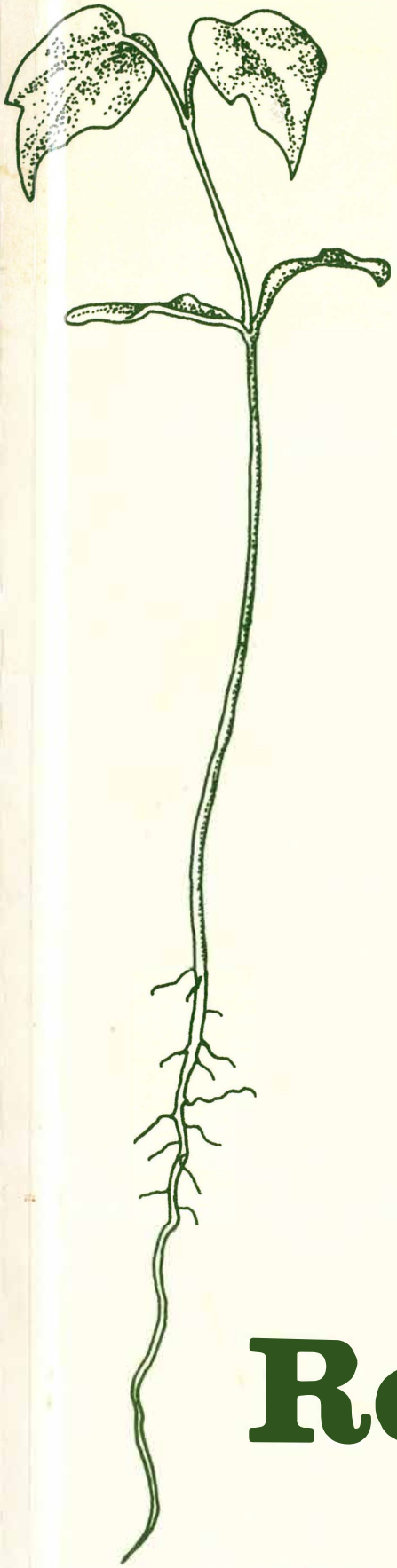
Winona, Minnesota March 2-3, 1982



PROCEEDINGS

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The University of Minnesota
Agricultural Extension Service
College of Forestry
Office of Special Programs

In Cooperation with

Minnesota Department of Natural Resources
U.S. Forest Service, State and Private
The Forest Industry of South-East Minnesota

Hardwood Regeneration Conference

FORWARD AND ACKNOWLEDGEMENTS

The Hardwood Regeneration Conference was long overdue. Field foresters working in the hardwoods of the North Central States have long felt that they were being neglected, and rightly so--for years they have requested new information and research to help them solve their specific problems in regenerating hardwoods. The Winona Conference was designed to respond to these requests. The attendance of some 160 registrants, mostly field foresters, reflected widespread interest in the program.

On the basis of attendance and many favorable comments regarding speakers and their program content, we feel the conference was a success. A successful conference requires considerable time and effort from many individuals and organizations. We would like to take this opportunity to thank the members of the Conference Planning Committee; the University of Minnesota College of Forestry and Extension Service; the Minnesota Department of Natural Resources-Division of Forestry; the USDA Forest Service-State and Private; Forest industries of southeastern Minnesota; the speakers for their excellent presentations, the moderators who handled the discussion periods; and last, but not least, all those in attendance.

NOTE: Questions and answers during the discussion periods appear after some of the speaker's papers. These were reproduced from tapes. Some of the discussion periods were not recorded on tape, hence the absence of questions and answers following these papers. We took the liberty to make a few minor editorial changes.

Harold Scholten *Carl Vogt*
Co-Chairmen, Hardwood Regeneration Conference
Planning Committee

TABLE OF CONTENTS

Page

FORWARD AND ACKNOWLEDGEMENTS---------- i

TABLE OF CONTENTS---------- ii

CONFERENCE PROGRAM---------- iii

CONFERENCE PARTICIPANTS---------- iv

INTRODUCTORY REMARKS By Dean Richard A. Skok---------- 1

REGIONAL CHARACTERISTICS AND FUTURE OPPORTUNITIES
ILLINOIS By Theodore W. Curtin---------- 3
IOWA By William C. Ritter---------- 5
MINNESOTA By Kenneth N. Anderson---------- 7
WISCONSIN By Adrian E. Hagen---------- 10

ANALYSIS OF GROWTH AND PHYSIOLOGICAL QUALITY IN HARDWOOD SEEDLINGS By R. E. Varmer, Jr.---------- 14

QUESTIONS AND DISCUSSION Moderated By Frank Irving---------- 20

NATURAL REGENERATION OF UPLAND HARDWOODS IN THE UPPER MISSISSIPPI VALLEY By Paul S. Johnson---------- 21

QUESTIONS AND DISCUSSION Moderated By Jerome Deden---------- 41

NATURAL REGENERATION OF BOTTOMLAND HARDWOODS IN THE UPPER MISSISSIPPI RIVER VALLEY By H. E. Garrett---------- 42

QUESTIONS AND DISCUSSION Moderated By Jerome Deden---------- 55

PRODUCTION AND HANDLING OF PLANTING STOCK By Paul W. Forward---------- 56

QUESTIONS AND DISCUSSION Moderated by Neil Broadwater-------- 65

MATCHING HARDWOOD SPECIES TO SITE By Paul Johnson & Edward M. Hayes--- 66

QUESTIONS AND DISCUSSION Moderated By Terry Helbig---------- 74

SELECTED HERBICIDE USES IN FOREST MANAGEMENT By Harvey A. Holt-------- 75

QUESTIONS AND DISCUSSION Moderated By Scott Reed---------- 82

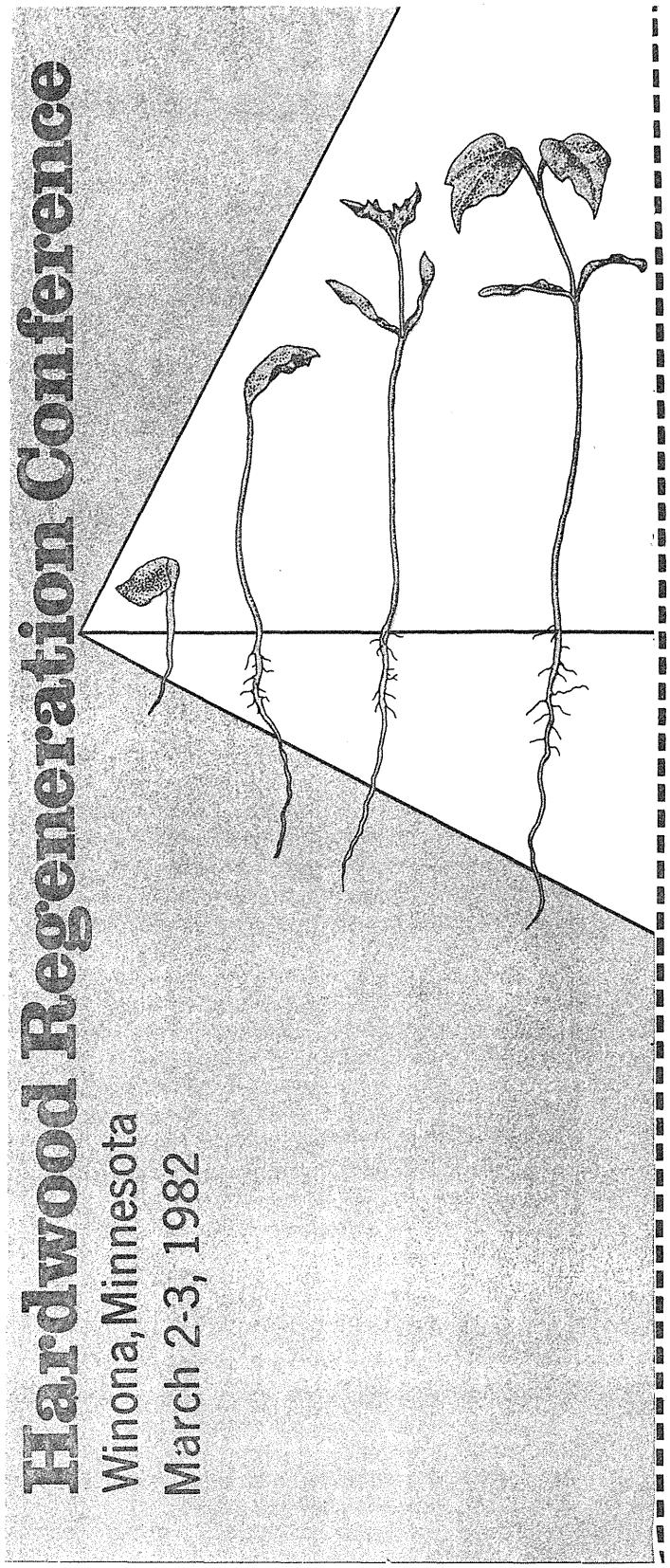
OPEN FIELD PLANTING By Edwin D. Godel---------- 86

HARDWOOD INTERPLANTING IN THE UPPER MISSISSIPPI VALLEY By Paul S. Johnson---------- 90

DIRECT SEEDING HARDWOODS IN THE UPPER MISSISSIPPI VALLEY By Ivan L. Sander---------- 110

IDENTIFYING AND CONTROLLING ANIMAL DAMAGE TO HARDWOODS By J. R. Kitts- 116

CONFERENCE SUMMARY AND THE NEXT STEP By Gregory N. Brown---------- 122



Hardwood Regeneration Conference

College Center
St. Mary's College
Winona, Minnesota
March 2–3, 1982

Educational Objective

Participants will exchange information and review current practices of hardwood regeneration and management.

Audience

Foresters, forestry technicians, nursery managers, administrative personnel and others interested in learning more about hardwood regeneration practices in central hardwood regions.

Fee

Preregistration is $30.00 per person.
Registration at the door is $35.00 per person.

The fee includes attendance at conference sessions, handout materials, Tuesday lunch, refreshments and proceedings.

The optional dinner on March 2 will cost an additional $9.00.

Conference Location

This conference will be held in the College Center of St. Mary's College in Winona, Minnesota. St. Mary's College is located on U.S. 14 just West of U.S. 61.

Registration

Monday, March 1, 5:00 – 9:00 p.m.
College Center Lobby

Tuesday, March 2, begins at 8:00 a.m.
College Center Lobby

Sponsored by

The University of Minnesota
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In Cooperation with

Minnesota Department of Natural Resources
U.S. Forest Service, State and Private
The Forest Industry of South-East Minnesota

Lodging

Participants are to make their own arrangements for lodging. Winona motels include:

Holiday Inn, U.S. 61 and MN 43, 507-454-4390
Sterling Motel, U.S. 61 and U.S. 14, 507-454-1120
Super 8 Motel, U.S. 61 and MN 43, 507-454-6066
Thrifty Scot Motel, U.S. 61 and U.S. 14, 507-454-6930
Westgate Motel (Best Western), U.S. 61 and U.S. 14, 507-454-2980

Program

Tuesday, March 2, 1982

Chairman — Harold Scholten — Room ABC

9:45 a.m. — Welcome and Introduction
— Richard Skok

Overview

Moderator — Carl Vogt

a.m.

10:15 Regional Characteristics and Future Opportunities
— Ted Curtin, Illinois
— Bill Ritter, Iowa
— Ken Anderson, Minnesota
— Adrian Hagen, Wisconsin

Silvics and Physiology

Moderator — Rodney Jacobs

11:15 Seedling Physiology and Growth
— Bob Farmer

Questions and Discussion
— Frank Irving

12:00 noon Lunch — Hall of Fame

Natural Regeneration

p.m.

12:45 Upland Hardwoods
— Paul Johnson

1:30 Bottomland Hardwoods
— Gene Garrett

Questions and Discussions
— Jerome Deden

2:30 Break

Artificial Regeneration

2:45 Production and Handling of Planting Stock
— Paul Forward

Questions and Discussion
— Neil Broadwater

4:00 Matching Species to Site
— Paul Johnson
— Ed Hayes

Questions and Discussion
— Terry Helbig

4:45 Adjourn

4:45 Social Hour — President's Room

Dinner following social hour (optional)
— South-Eastern Minnesota, A Look at the Land and the People
— Bruce Fuller

Wednesday, March 3, 1982

a.m.

8:30 Herbicides
— Harvey Holt

Questions and Discussion
— Scott Reed

9:30 Open Field Planting
— Ed Godel

10:00 Interplanting
— Paul Johnson

Questions and Discussion
— Bruce Brown

10:30 Break

10:45 Direct Seeding
— Ivan Sander

11:05 Identifying and Controlling Animal Damage to Hardwoods
— James Kitts

Questions and Discussion
— Patrick Weicherding

11:30 Conference Summary and the Next Step
— Gregory Brown

Optional Field Trips*

Hosted by Minnesota Department of Natural Resources

1:15 p.m. Hardy Woods and Vicinity — Ken Anderson

Southeastern Minnesota Hardwood Area — Terry Helbig

*Car tour field trip leaders will be available. Sign-up sheet for tours will be available at the Registration Desk.

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** CONFERENCE SPEAKERS/PAPER PRESENTERS

INTRODUCTORY REMARKS

R. A. Skok
Dean, College of Forestry
University of Minnesota
St. Paul, Minnesota

The topic of this conference is both timely and appropriate for all those with a professional and scientific interest in the forests of the central hardwood region. The value of these forests lie not only in the timber they produce but in the landscape diversity they offer, the watershed protection they afford, and the recreational and wildlife opportunities they represent.

Largely owned by the notorious class of individuals euphemistically labeled as "nonindustrial private owners" these forests present a special challenge to foresters. With more than 75 percent of this forest acreage in such ownership one could hardly devise a scheme for a more decentralized and pluralistic institutional setting to control such a resource. In your attempt to meet this challenge we endorse strongly your decision to gather in Winona for the next day and one-half to explore what is known and what is unknown about regeneration of this large and complex forest system.

The current stresses in our economy are bringing about a more far reaching adjustment in the forestry sector than most anyone would have forecast even 18 months ago. When the full implementation of these changes are clear, one likely result will be some regional shifts in relative proportions of forest product output and in recreation use. A resource such as that represented by the eastern hardwoods of the U.S. has become increasingly attractive and will be even more so in the decade ahead as these forces work themselves through the market place.

Recent projections by a private firm indicated an expected increase of 4.2 million cords of harvested hardwood pulpwood in the east over the decade through 1988-89. In total this would represent a 42 percent timber harvest increase to meet requirements for pulp and the newly established waferboard/ OSB plants. When one couples this with cutting needed to meet the reemergence of firewood use so preveleant across the northern states the past 7 or 8 years, the challenge is there to assure that these forests will receive the attention they need to enhance their future productivity of the values we know they can produce. To do this the silvicultural practices used must be based both on knowledge that will achieve the future forest composition and structure desired by the owner and persuasive to that owner. The alternative is that the owners continue to accept potluck in the nature of their future forests.

This conference will explore the state of the art and science of central hardwood regeneration. I would hope at least three things happen during and as a result of these explorations. First, each of those present leave here with <u>at least</u> one idea that is new and important to them on how to approach hardwood regeneration. Second, as the opportunity provides itself, please share your own experiences and observations on the topics at hand. Some of the most valuable outcomes of conferences such as this are such shared insights. Third, it would be valuable to those of us in research and education if a sense of the major problems you face in practice and the priorities you

attach to such problems can be identified as the conference proceeds. I will not be surprised if this conference raises more questions than it answers along these lines.

In closing, I wish to express my appreciation to those who served as members of the Conference Planning Committee and to those who agreed to serve here as speakers or moderators. The agenda appears to be well planned and comprehensive. Good attendance has been achieved. Thus, the elements are in place for a successful meeting.

REGIONAL CHARACTERISTICS AND FUTURE OPPORTUNITIES
-ILLINOIS-

Theodore W. Curtin
Extension Forester
University of Illinois
Urbana, Illinois

The American prairies begin in Illinois. The Illinois-Indiana boundary is the beginning where many tree species fade and those remaining form the long fingers of woodlands along the streams and rivers of Illinois. When white-man first arrived the forest covered 42 percent of the land; today many guesses place the forest cover at no more than 10 percent. The tall grass prairie and marsh land has also given way to the modern prairie.

The forest ownership pattern is nearly all private nonindustrial holdings. Unfortunately the tenure of many family farms or other types of private ownerships are short and often interrupt management plans through early sales, total neglect and abuse, or outright land clearing.

Another factor quite prevalent in the farm belt is the absentee ownership. This may be an insurance company, a bank, or private investor. Forest management under these ownerships is difficult. I have yet to encounter a tenant who has in his lease, some provision or reference to the management of the timber on the farm he is renting.

The natural forests of Illinois are predominately deciduous and the species composition is very large as might be expected in a state 400 miles from north to south. Cucumber magnolia and cypress are native to our southern counties while paper birch and tamarack are native to the northern counties. I recall a quarter acre growth demonstration plot in southern Illinois that contained 17 different species.

Most forests of Illinois have been subjected to various abuses including fire, grazing, poor cutting practices or some combination of these. This neglect coupled with the exposure to drying winds of many small prairie tracts has caused slow and irregular development.

Fire has generally resulted in butt scars and subsequent butt rot of otherwise good trees. Grazing has often damaged or elminated reproduction, injured the surface roots and compacted the soils. Poor cutting practices have generally taken two forms: (1) "high grading" by removing only the best trees and (2) commercial clearcutting. High grading the best of trees while leaving all the poorer ones, and making no provision for regeneration of the more desirable species, quickly leads to a low-quality forest. In commercial clearcutting the operator takes all the merchantable material, usually to a low diameter limit, and leaves only culls, poor quality and less desirable species to occupy the area.

Thus fire, grazing and various abuses in harvesting, together with the wide range of sites and species, have left a large variety of forest conditions beset with major problems.

The oaks, as a group, comprise the major portion of the Illinois forest.

Their regeneration has left much to be desired and has given way to a group of hardwoods--mostly yellow poplar, cottonwood, sycamore, and sweetgum. At any given location, a variety of species such as ash, elm, hackberry, hickory, etc., might be the dominant reproduction.

The upland sites in both northern and southern Illinois contain three broad types: (1) mixed hardwoods, (2) mixed oaks, and (3) oak-hickory. The bottoms of southern Illinois may contain mixtures of mostly soft hardwoods (silver maple, green ash, sycamore, sweetgum, elm, cottonwood, cherrybark, oak and swamp white oak, and boxelder) or mostly hard hardwoods (hickory, pecan, pin, swamp white, and cherrybark oaks, green ash, elm, silver maple, tupelo gum, and cypress). Cottonwood is common in the well drained alluvial bottoms. The northern Illinois bottomlands are either cottonwood or mixed bottomland hardwoods (silver maple, elms, sycamore, black walnut, green ash, buckeye, river birch, hackberry, honeylocust, cottonwood, bur oak, swamp white oak, and pin oak).

The condition of the bottomland stands are generally superior to those of the slower developing upland stands. Some abuse is not uncommon, however, and appears as limbly elm, boxelder, hackberry, and honeylocust.

Advance oak reproduction varies greatly from stand to stand in both quality and quantity. It appears as 10 to 12 inch plants that may be 25 years old or brushy ill-formed specimens 3 to 5 feet high of much younger age. It is apparently much more tolerant than we once thought and while it may exist on poorer sites it does not grow and develop well even when released. This is at least in part because of deteriorated site conditions and the presence of a multitude of rapid growing junk species (elm, black locust, sassafras, etc., including a variety of shrubs).

Someone once said that "a good forester is a practicing ecologist". He attempts to manipulate cutting practices to create the most favorable conditions for regeneration. There are times when a harvest might best be delayed until advanced reproduction is established.

Frequently, we get species we do not want because nearly all our hardwoods will survive and grow on a variety of sites. Most hardwood forests in the Central States are the result of natural regeneration and the lack of management. We all know what an untended garden looks like, but we seldom view a forest with the same degree of concern.

How often is a harvest planned to coincide with a good seed crop? Almost never. We seem content to take what comes whether from seed, sprouts, or luck. And if we are lucky, maybe fire will be delayed until the new crop is of sufficient size to survive.

An early thought that firewood interest might be an opportunity for T.S.I. quickly faded. We now view it as a real threat to the development of highly valued dense hardwoods.

Maybe we foresters have been too complacent or naive in trying to let Mother Nature plant our forest. Our farmer friends gave up years ago and now plant what they want. Forestry has been practiced in Europe for hundreds of years and they plant rather than rely on nature for the next crop. The words for the rotation should be even-aged management, clear-cut and plant what you want.

REGIONAL CHARACTERISTICS AND FUTURE OPPORTUNITIES
-IOWA-

William C. Ritter
Regional Forester
Iowa Conservation Commission
Ames, Iowa

It's a pleasure to be here not only to extend to the conference the support of our State Forester, Gene Hertel, but from a purely personal position of being able to participate in an endeavor that may lead to answers on regeneration, those answers so badly needed by our field foresters.

Very briefly--I offer an overview of how things are in Iowa and the problems facing the forestry program. In a state where corn, beans and livestock are the name of the game--the economic climate doesn't lend itself to forests. As a matter of fact, Iowa is losing forest acres to other uses at an alarming rate. Nearly 40 percent of our commercial forest acres have been converted in the last 25 years. Our forest industries are geared to hardwoods, primarily oak, whereas the climax forest type is northern hardwoods. The State Forest Nursery has problems of both soil and area, limiting species production both in kind and number. And we're still faced with that never ending problem of providing our field foresters with the data necessary to make silvicultural decisions based upon fact.

Well, things are so bad in Iowa it appears as though we have given up. That is not the case. We still have 1½ million acres of commercial forestland, so it's not all corn yet. With the assistance of Iowa's Forest Industries an aggressive program enlisting the support of our legislators in addressing our forest problem has begun. The Iowa Section of the Society of American Foresters is taking the initiative to coordinate the direction of all groups and individuals concerned about Iowa's forest resource. And, in the planning stage is an expansion of our nursery facilities to a more complimentary location.

Now that I have endeavored to be more positive, the fact remains, one problem, that of regeneration and its relationship to the person in the field is still to be solved. This particular problem applies to the Eastern Region, and more specifically, to the "Driftless Area" -- some 250,000 acres of prime forestland including all or part of seven counties. The characteristics of this area are shared to a limited degree with Illinois, Minnesota and Wisconsin. In Iowa, this is known as the Paleozoic Plateau, consisting of Cambrian rocks--sands, shales, limestone--little to no loess, steep valleys, caves, sinkholes, springs and, of course, forest cover. The predominant soil types are Fayette and Dubuque. These excellent forest soils produce quality timber in mixed, northern and some bottomland hardwoods. Oak, the predominant species, often has difficulty in regeneration unless helped. Advance regeneration of acceptable species is often absent, the exception being northern hardwoods. Ferns are often the only ground cover and junk species such as ironwood and prickly ash abound.

Iowa welcomes the opportunity to participate in this conference. Although much research has been done in the past, it has not been readily available to the person in the field. At the completion of the conference it should be

evident that gaps exist where variables affecting regeneration are concerned. Iowa is concerned with the manner in which these gaps are addressed. Will it be a rehash of the existing data or is applied research one of the solutions? Do we need a standing committee with representatives from the concerned states and the U.S.F.S. to address such questions as applying existing research, identifying needs for additional research, or identifying needs for applying or conducting research in other aspects of forest management whether it be silvicultural or economic.

My thanks to the State of Minnesota and all the people involved and to the U.S.F.S. Have a good conference.

REGIONAL CHARACTERISTICS AND FUTURE OPPORTUNITIES
-MINNESOTA-

Kenneth N. Anderson
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Department of Natural Resources
Rochester, Minnesota

As I listened to Ted Curtin and Bill Ritter describe the characteristics of hardwood forests in their states, I noted the close similarity to the situation here in Minnesota. I'll just add a few remarks and observations from my experience with our hardwood stands to give you a general idea of our resources.

If we look at the hardwood forest area in Minnesota we find a very large area. (From 1.5 to 2.5 million acres depending on where you draw the line. See map.) The wooded areas occur generally within the agricultural zone of the state along the drainages and rivers and as scattered woodlots, gradually changing to the aspen and pine stands in the main forested area of the state.

A good share of this acreage (43%) is in the northern hardwood type. Generally speaking, there are few problems in regenerating the stands if the cutting follows the prescriptions shown in the Management Guide for Northern Hardwoods. If there is a problem, it is that since most lands are privately owned, the cutting is often a matter of economic opportunity, a forester is not involved, and little thought is given to timing the cut, the residual left, or age of the stands.

The bottomland hardwood type (18%) is a different matter. Regeneration can be a problem if the stand is opened up to a point where heavy herbaceous understory prevents establishment of new seedlings or if the water table is high enough to prevent seedling establishment. This is especially true on the first and second benches. There is not a lot of research available on stand prescriptions for bottomland hardwoods and this is one area where research can help the field forester.

The balance of the hardwood stands occur in the oak type (central hardwoods). Because of the wide geographical occurrence, a wide diversity of stands exists in this type. Those stands on sand soils generally reproduce with little effort or problems. The northern fringe area is mixed with aspen and if cut too heavily, will result in sprouting of aspen which competes with desirable reproduction.

We have one major problem area, the unglaciated portion of the region (4 states) and the adjoining area of postglacial windblown loess. Here we have a unique hardwood mix which in actuality is a transition between the (oak-hickory) and (maple-basswood) types. Most of these stands vary in composition generally as a result of past practices. Before settlement, repeated fires led to development of these stands, and of course since then the burning has been greatly reduced.

Heavy grazing 50-100 years ago was a common practice and continues today but at a reduced level. Heavy cutting with little consideration to the available

reproduction or seed sources--all of these factors contributed to a mosaic of different stands of various species composition. (On Forest Inventory, we commonly find 14 or more species in an upland stand.)

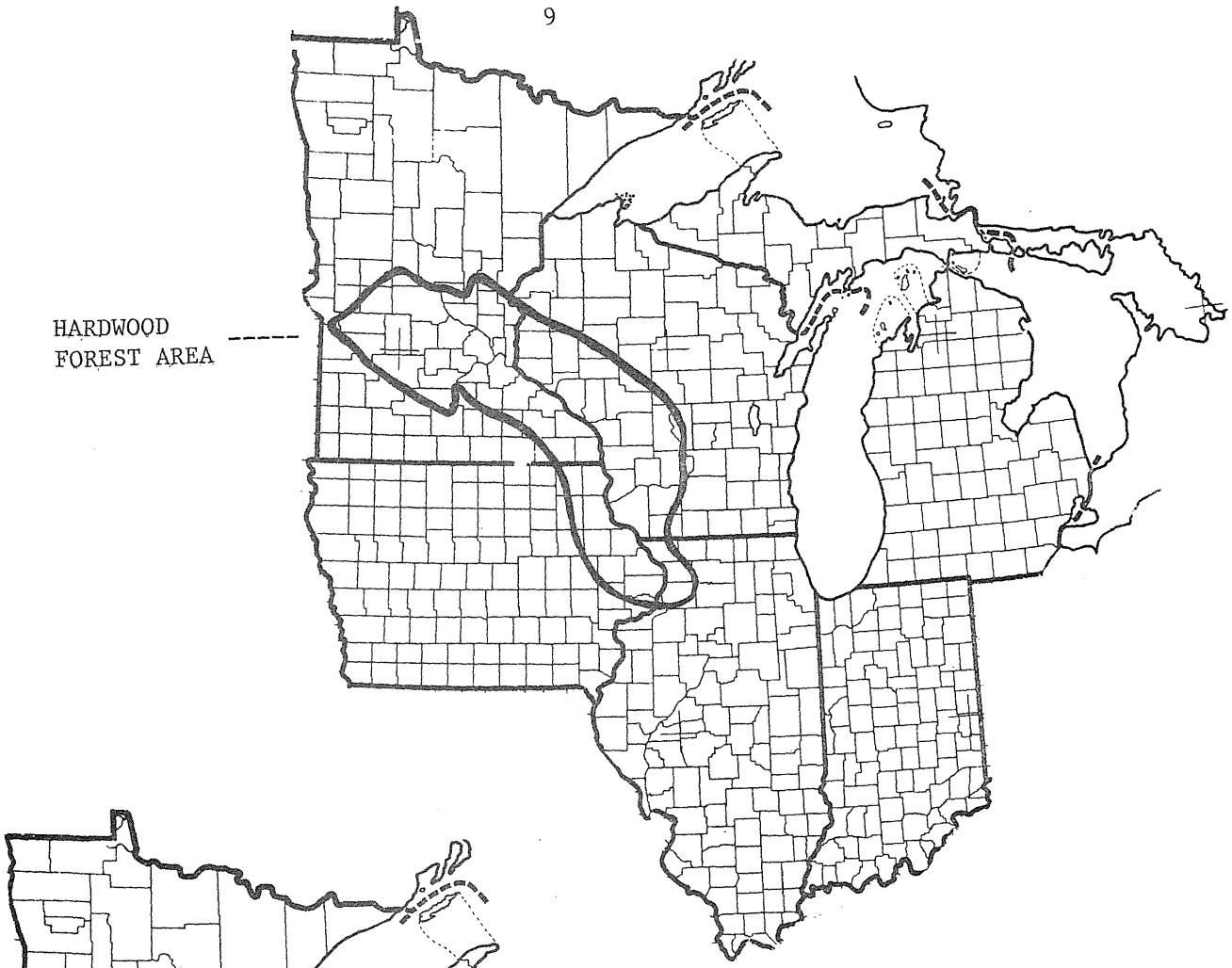
Over the years I've seen attempts by foresters to apply various silvicultural systems to these stands from selective cuts to shelterwood cutting to clear cuts. The results have varied but generally we find a decided lack of oak regeneration. When we have succeeded we often have difficulty in duplicating the conditions to repeat these successes, which is obviously very frustrating to the field forester.

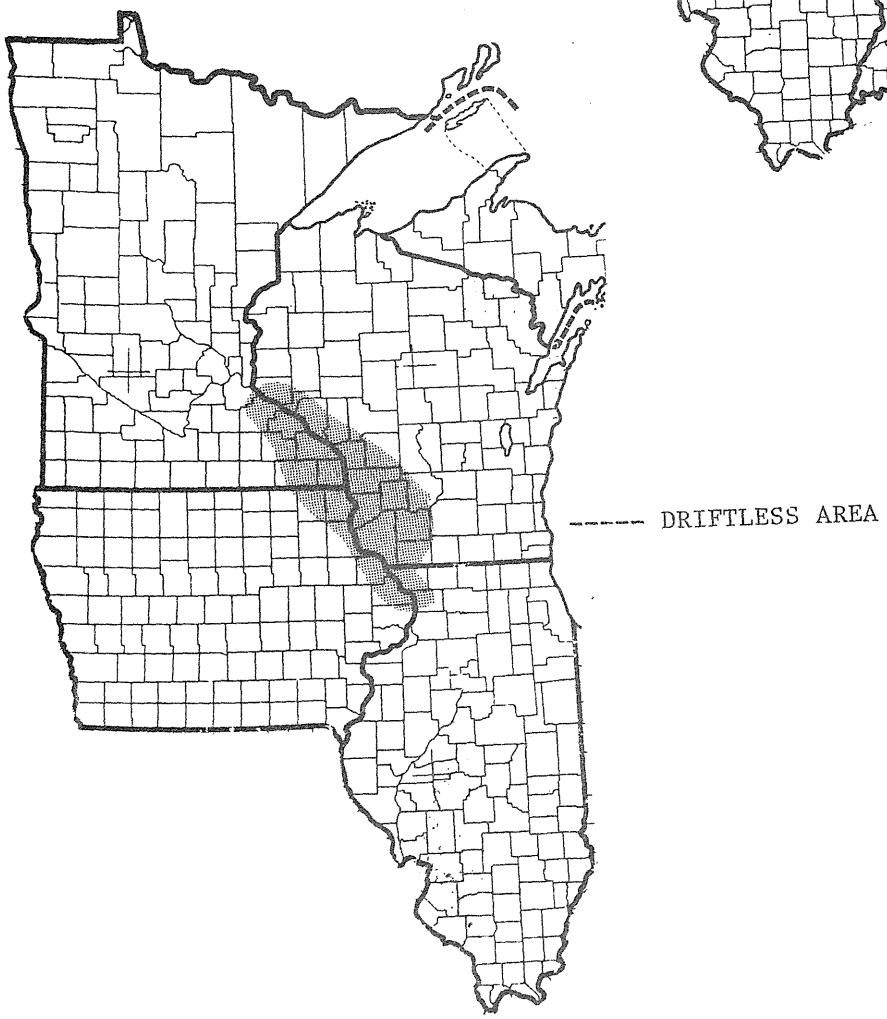
We need to find practical cutting prescriptions to adequately reproduce our stands. What are our alternatives? 1) Can we rely on seeding or sprouting? 2) Can we improve the stocking and composition by inter-planting? 3) If we cannot expect good results with oak what about other species? 4) Should we do nothing and go trout fishing instead?

Research has found answers to some of these questions and I welcome this conference as a way of sharing today's "state-of-the-art" with each other. I'm sure some questions will remain unanswered so as we listen to our speakers today and tomorrow, I hope that first of all we can conclude that continued research is still needed to answer these problems.

I further hope that the interest shown here will challenge the university systems and experiment stations to help "our foresters" by providing such research on a more site specific basis (i.e. within this geographical area).

In conclusion I'd like to suggest that those studies could be accomplished on public lands in cooperation with the states! I see that as a perfect match, the brains of research and the brawn of the practicing forester. I hope we can build on this! Thank you.


HARDWOOD
FOREST AREA


DRIFTLESS AREA

REGIONAL CHARACTERISTICS AND FUTURE OPPORTUNITIES
-WISCONSIN-

Adrian E. Hagen
Area Forester
Wisconsin Department of Natural Resources
La Crosse, Wisconsin

WISCONSIN'S FOREST TODAY

I'd like to begin with a look at Wisconsin's forest resource. The state is 43 percent forested, with a total of 14.9 million acres, of which 14.5 million is commercial forestland. Sixty percent of it is privately-owned. Oak-hickory is the third largest forest type at 2.7 million acres or 18.6 percent of the total. The largest is the aspen-birch-beech types (29%) with maple-birch-beech the second largest at 24 percent of the commercial acres. Elm-ash-cottonwood, or the bottomland hardwoods, are fourth with 7.5 percent.

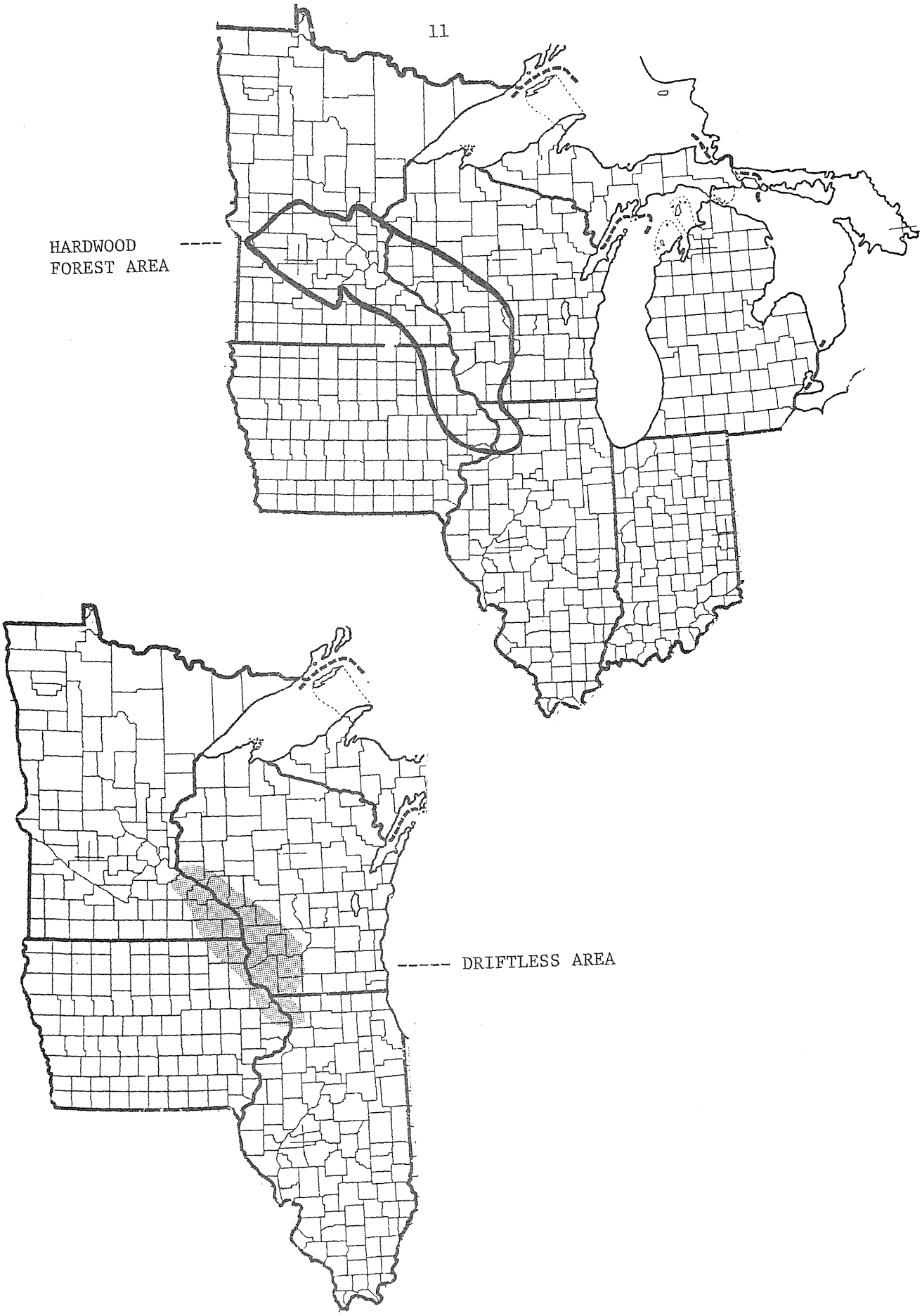
The Driftless Area of the state (see map) encompasses approximately 5 million acres of which 1.5 million is commercial forest. Forty percent is in oak type (excluding scrub oak), which is one-fourth of the oak type in the state.

The La Crosse Area (La Crosse, Vernon, Crawford and Monroe Counties) spreads across the center of the Driftless area and is quite typical of its timber types. Of its 583,000 acres of commercial forest, one-third is oak type. These figures point up the fact that the oak timber type is a significant forest type in Wisconsin.

OAK STAND CHARACTERISTICS

A sawtimber oak stand, and fifty percent of the Driftless area type is sawtimber, has many rather typical or common characteristics. It is composed of predominantly sawtimber-sized trees, ranging from 3000-7000 board feet per acre. Stands can also be found that will have 10,000-12,000 feet per acre to a possible high of 16,000. There is little advance oak reproduction, however, hickory, elm, aspen, white birch, cherry or boxelder are noticeably present in most cases. There is a dense understory of dogwood, hazel, prickly ash and other shrubs. Ferns are very dense also on good mesic sites. The stands are of an advanced age (100-120 years) and deteriorating. Along the Mississippi, they are also on very steep terrain. Generally the stands have a grazing history, oft-times a fire history and usually have had some cutting done in them. Much cutting has been done for fuelwood and home-use lumber over the years. In some areas along the river there were substantial cuttings for steamboat wood during that era and during dam construction in the late 1930's for pilings. Such cuttings have resulted in nice young oak stands. The oak resource is highly prized by the industry for veneer, lumber and railroad ties.

It is not uncommon for these same situations to occur in bottomland hardwoods, another type we really have little management information on. There has been less of a fire problem there but more grazing and cutting. The theory still prevails, particularly with some loggers, that these stands can be cut every twenty years. That's alright to a point until the stands are too old to respond, as they are now.


HARDWOOD
FOREST AREA
---- DRIFTLESS AREA

PROBLEMS

The problems in hardwood reproduction are basically four, as I see them:

1. Lack of advance reproduction in oak, a statewide problem. It is more variable with bottomland hardwoods.

2. Invasion of inferior species and brush.

3. Lack of proven silvicultural techniques to establish reproduction and develop it to the point where it will provide a well-stocked stand of oak.

4. Need for hardwood planting stock of a quality which will grow rapidly after planting and compete favorably with other forest vegetation. Although most stands are reproduced naturally, there is a place for planting.

MANAGEMENT PRACTICES

Selection silviculture was used in Wisconsin through the 1950's. Much timber stand improvement was done in stands too old to respond. Due to their advanced age, trees were not growing into the sawtimber classes to replace those harvested. Brush developed rapidly in openings, inhibiting reproduction.

The shelterwood system has also been used, to a greater extent elsewhere in the state. Although seedlings result from this system, they are lost within 2-3 years. The shrub layer increases substantially with this system. A practical method to control the brush would be needed for shelterwood cutting to contribute to solving the regeneration problem.

Upland central hardwoods management came into use in the early 1960's. Currently, even-aged management is used with clearcutting as the regeneration cut followed by post-sale treatment, cutting all residual stems greater than 2 inches DBH. We rely on any advance reproduction, seedling sprouts, and stump sprouts to form the new stand.

Many new stands develop into mixed hardwood stands. They are far from pure oak but may be more nearly so in 40-50 years due to the pioneer species dropping out. A recent survey of five fifteen-year old stands in Trempealeau and Buffalo Counties (N.E. across the Mississippi from Winona) counted all oaks 4½ feet and taller. Two stands had more than four hundred oak stems per acre, adequate numbers to provide a good stand to manage.

Stands with the most advance reproduction are generally those of lower site quality on south or west aspects (or dryer portions of other aspects). These stands may turn out to be the bulk of the future oak type, except for an oak component on good sites. A similar conclusion is also drawn in the U.S.F.S. Oak Manger's Handbook.

There are sizeable areas along the east and north sides of the Driftless Area where northern hardwoods are invading. They are present in larger numbers in

the advance reproduction and also in the new stand. Being more valuable species, they are readily accepted. Most likely we are seeing a movement toward a northern hardwood climax forest.

On Wisconsin's private lands, the usual statistics regarding ownership turnover and a variety of landowner objectives apply. Many owners are not particularly interested in just a financial return or a particular species of trees, such as oak; any trees will satisfy them. However, foresters do have many opportunities for improved management in the oak type and we need some practical methods to maintain a strong oak component on our good growing sites.

ANALYSIS OF GROWTH AND PHYSIOLOGICAL QUALITY IN HARDWOOD SEEDLINGS

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Whether we are growing container or bare-rooted stock the objective is the same: stock which will survive and grow rapidly. This usually means that we should grow material as large as possible within time constraints and that material must be of good physiological quality. To do this we manipulate environmental resources and as a consequence obtain differences in performance. We also commonly observe major species differences in growth within a single environment. These are due to variation in the way species are genetically programmed to use environmental resources.

In this discussion I will examine some of the reasons why we obtain these differences in growth and physiological quality. In other words, I would like to examine the physiological basis of differences in the development of seedlings. The analytical examination of these differences has been called yield component analysis. For example, variation in shoot growth, whether due to environmental or genetic reasons, is related to variation in the frequency, duration and rate of shoot elongation. Each of these characteristics may be controlled by different physiological mechanisms which we may manipulate to alter shoot growth. Therefore yield component analysis is a way of considering growth differences in a physiological or genetic context and of asking, "Why is this plant larger than that plant?" It is an analytical way of viewing variation which may help us manipulate variation. The concept may be especially useful to analyzing and manipulating short-term growth, e.g. in container or nursery production of planting stock.

Consider the concepts and methods of yield or growth analysis as a framework for evaluating the components of growth in hardwoods. Detailed treatments of these ideas are presented by Evans (1972) and Ledig (1974). First, Relative Growth Rate may be viewed as the interest rate of plants:

$$\text{Relative Growth Rate} = \frac{dW}{dT} \cdot \frac{1}{W} = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1}$$

It is computed by measuring (via sampling) weight at Time 1(T_1) and Time 2 (T_2), then determining the rate of change in weight (W) over time. Rates may typically vary from <100 mg/g/wk to >700 mg/g/wk in tree seedlings. We wish to get best rate possible given our genetic and environmental resources, and to distribute the product (of this rate) on the seedlings so as to get a high quality plant in terms of survival and growth.

Variation in Relative Growth Rate is the consequence of variation in two components 1) the amount of investment in leaf surface as a proportion of the organism and 2) the assimilation rate of these leaves on a unit leaf basis, i.e. per cm^2 . The investment in leaves (or production capacity) may be expressed as a Leaf Area Ratio, or ratio of leaf area to total plant weight.

$$\text{Leaf Area Ratio} = \frac{\text{Leaf Area}}{\text{Weight}}$$

The Net Assimilation Rate is the rate of weight gain expressed on a unit leaf area basis, i.e. grams of gain per cm^2 of leaf per week. This can be calculated if we know weight (W) and leaf area (LA) at Time 1 (T_1) and Time 2 (T_2).

$$\text{Net Assimilation Rate} = \frac{DW}{dT} \cdot \frac{1}{LA} = \frac{W_2 - W_1}{T_2 - T_1} \cdot \frac{\log_e LA_2 - \log_e LA_1}{LA_2 - LA_1}$$

It can therefore be shown that:

$$\text{Relative Growth Rate} = \text{Net Assimilation Rate} \times \text{Leaf Area Ratio}$$

$$\frac{dW}{dT} \cdot \frac{1}{LA} = \left(\frac{dW}{dT} \cdot \frac{1}{LA}\right) \cdot \left(\frac{LA}{W}\right)$$

So when we wish to manipulate Relative Growth Rate we must work with these two components and with the factors which influence the way products of leaves are distributed to roots and shoots. This distribution pattern might be considered a third yield component. In growth analysis we consider how genetic and environmental controls influence each of these components.

Consider first genetic variation in these components of growth. There is an enormous amount of genetic variation in most hardwoods, and it can be quickly and effectively used in planting stock production. For example, in eastern Tennessee 1-0 white oak (Quercus alba L.) seedlings, as commonly grown, are too small for good planting stock.

In the mid 1970's we began examining white oak growth with the aim of finding components which would be most ammendable to manipulation. To do this, we used the growth analysis concepts which I've just described. In the course of the work we noted some major family differences in number and size of initial leaves, i.e. those developing from primordia in the seed. We subsequently found out that genetic control over initial leaf area is strong and observed that open-pollinated families with higher leaf area contained one-year-old plants substantially larger (30%) than average (Farmer and Cunningham 1980). We also noted that Net Assimilation Rate and the growth rate of leaf area were modestly correlated with Relative Growth Rate. But the major contributor to better seedlings was capital invested in initial leaf area. Therefore, one important key to good growth is manipulation of initial capital, i.e. Leaf Area Ratio; genetic manipulation may be the simplest.

Another approach to early investment in assimilation capacity is to develop better control over the time of germination. Our growing knowledge of population biology and seed germination suggest many ways in which we can develop these controls. For example, black cherry (Prunus serotina Ehrh.) seed has two characteristics important in timing germination to take advantage of the entire growing season. First, as it completes its chilling requirements cherry first develops a capability for germinating better at low temperatures than at higher temperatures (Farmer and Barnett, 1972). Therefore, if one stratifies the seed and sows in the spring, the relationship between chilling time, bed temperature and seeding time become important. There is another complicating factor. At least some open-pollinated families of black cherry exhibit what is known as genetic polymorphism in germination pattern. Some seed in these families require one chilling period and others apparently require two--or a very long single period. Under natural conditions

this spreads germination over two seasons and is of some fitness value to the species. Under nursery conditions this means that we get partial germination the first year, and the next year the remaining seeds germinate. The "take home lesson" is that we must know how individual families operate if we want to control timing of germination. Yellow poplar (Liriodendron tulipifera L.) exhibits the same sort of polymorphism, but it is apparently much more complicated (Barnett and Farmer, 1978).

While my talk is mostly concerned with controlling the performance of individual plants, I would be remiss at this point if I did not mention the new interest in regeneration as a problem in plant population biology. The concept of genetic polymorphism in germination is just one of many notions which have come out of this area of investigation where genetics, physiology, and ecology are integrated in considering how populations operate (Harper, 1977). The concepts include those of seed rain, seed banks, the basic nature of competition and self thinning, species interactions of various sorts, all applicable to hardwood regeneration.

Given the right sort of attention to initial leaf area, the next step is to increase Net Assimilation Rate as much as possible given existing environmental constraints. Obviously these constraints will vary depending upon whether one is growing container stock in a greenhouse or using outdoor beds. In container production one can completely control nutrition, moisture, atmospheric CO_2, temperature, genotype and have partial control over light. All have been shown to influence Net Assimilation Rate, though only recently have we tried to combine conditions to get the best possible rate. Usually we study individual factors. For example, consider Madgwick's (1971) study of the way in which nitrogen influences Net Assimilation Rate and other aspects of yellow poplar growth. Madgwick grew yellow poplar in nutrient solutions in a greenhouse and varied nitrogen from 0 to 200 ppm. In his growth analyses he observed several important relationships: First, Relative Growth Rate did vary, with the optimum nitrogen concentration at about 100 ppm. Second, Leaf Area Ration was little influenced by nitrogen level. Third, Net Assimilation Rate was positively correlated with Relative Growth Rate.

This suggests that one should concentrate on improving rate of photosynthesis, and some work with, for example, Populus (Gordon and Promnitz, 1976) has indicated that genetic variation in growth may be correlated with assimilation rate.

Usually, however, Leaf Area Ratio and Net Assimilation Rate are both positively related to growth. Growth differences in northern red oak (Quercus rubra L.), induced by varying light and temperature, have been associated with differences in Net Assimilation Rate and the degree to which plants reinvest assimilate in leaf area (Farmer, 1975). Species differences in Relative Growth Rate are also related to variance in both leaf area growth and assimilation rate, and the relationship between these two components of yield may vary with species (Farmer, 1980). Because of this, production strategy will necessarily be tailored to individual species--and perhaps to specific genetic material.

Getting suitably large plants is an essential first step, and we do this by manipulating Leaf Area Ratio and Net Assimilation Rate. However, we must

also make sure that the plant represents a reasonable balance of shoot and root, and that it's physiological status is such that good survival and early growth are possible. We can, of course, always prune large plants to get the proper balance. This is expensive. More commonly we will try to use environmental manipulation to control the relative growth of shoot and root. Ideally, we would obtain desired height and leaf area, then reduce day-length and alter temperature to set apical buds and use subsequent assimilation to stock the plant with stored food. This means stimulating development of more shoot and root area in which starch and other reserve materials can be stored. This strategy depends upon knowing enough about growth controls to exert some control. For many hardwoods we are far from applying well known physiological information on shoot growth. In others (e.g. the oaks) we still lack basic knowledge, though much progress has been made in the last decade (Reich et al 1980, Johnson and Garret 1981). As a consequence of either circumstance we still usually increase moisture stress and reduce fertilization to control shoot growth. These two actions don't help plant assimilation and storage much. Under container systems we can and should do a lot more with temperature and photoperiod.

As I've noted, the purpose of this control is to develop storage capacity and fill it with, for example, starch. While starch is not the only major storage material, it is probably correlated with other important storage materials and could be used to evaluate physiological status more. Certainly starch is the easiest to measure on an operational basis (Wargo 1975). We know something of the pattern of starch accumulation in stock of Appalachian hardwoods and have observed that the major period of accumulation is in the fall after apical growth has stopped, but when leaves are still on plants (Farmer 1978). Thus, premature fall defoliation may result in reduced starch storage (Larson 1975).

Manipulation of accumulation requires knowing how to control apical growth of shoots and roots and how source-sink relationships work. The concept of source-sink refers to the physiological relationship between those portions of plants which photosynthesize and those which use the photosynthate. There is now evidence that activity of a sink (for example, a storage site such as a large root system) influences assimilation rate (Geiger 1976). Thus, adequate storage area (e.g. large roots) and a suitable environment may promote assimilation to fill the area with starch. Very close to this concept of shoot and root as source and sink is the notion that the root environment influences not only root growth, but performance of the shoot. For example, it has been shown that a number of leaf processes (e.g. photosynthesis, transpiration) are affected by root temperature (Cooper 1973). The physiology of these kinds of relationships are not well understood, but we should be aware of their existence as we attempt to control seedling growth.

The producer must also know about manifestations of seedling quality and their relationship to characteristics of high quality stock. By manifestation of quality we mean survival and growth. One of the keys to survival and growth is the capacity to quickly regenerate roots. This is, of course, controlled by the environment in which the tree is planted. It is also probably related to the physiological status of the tree. While we haven't

fully demonstrated that root regeneration is closely associated with other features of physiological quality in hardwoods (e.g. starch levels), we have learned a few things about how root regeneration operates (Farmer 1979, Larson 1970, Webb 1977, Reitveld and Williams 1978). In brief, initiation and growth of new roots on a seedling is controlled by some stimulus which originates in non-dormant buds on the stem. When the buds are physiologically dormant, (i.e., before chilling in the fall) very little root growth will take place even under a good environment in many species. As chilling progresses the plant gradually develops root regeneration potential. The shoot can be replaced (in terms of stimulating root regeneration) by the auxin type of growth regulator. These hormones are believed to originate in buds. In oaks the more buds on a shoot, the better the root regeneration. So top pruning may have a negative effect. However in sugar maple, the roots of which do not exhibit true winter dormancy, shoots have been shown to compete with root growth (Dumbroff and Webb 1978).

To summarize, in order to most effectively produce and use hardwood planting stock we must 1) understand and be able to manipulate individual processes and plant materials, 2) analytically consider physiological processes as components of the total production system to determine where we can most effectively manipulate growth, 3) know about the components of seedling quality and their relationship to plant processes. The concepts of growth analysis and yield components can form a useful framework for considering these three parts of the job, whether we are doing research or trying to produce better stock.

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QUESTIONS AND DISCUSSION

Question: What effect does top pruning in walnut have on root regeneration?

Answer: (Bob Farmer) I haven't done any work with walnut. I believe, though, you probably would not have the same problems you would have with oak. I think it would be perhaps of some benefit if your top was so large that you were going to overbalance your root system. The whole reason for doing any top pruning is based on the assumption that you have too much leaf area in your top. And, therefore, you are going to put the root system that you have available to you under stress when all those leaves start growing. If you have a real healthy root system it can put up with a lot more leaf surface. Of cource it is going to photosynthesize and this is going to promote root growth. So, there is not an inherent advantage of top pruning. I think you have to look at the size of the root and the size of the stock that you have to work with and the blanace of shoot and root. And, if the shoot looks like it is going to overbalance the root system, well then you might consider top pruning. So, we need to look at the physiological situation each time before we make a pruning prescription.

Question: What about root crowding in containerized stock?

Answer: (Bob Farmer) Well, the data that I've seen, and its all been from conifer data, looks like it is something that you really need to take into consideration fairly strongly. We have seen some of the trees that have been examined after they have been in the ground a good while that have resulted from root compaction or one thing or another and some of this hangs in for a long time. I think that you probably have the same situation in hardwoods. My tendency, if you have grown hardwoods in containers for a long period of time and you do have a lot of root compaction, would be to do some root pruning so that the new root system that regenerated would not have the conformation of the old roots. Probably if Dick Tinus were here he could give you a lot better answer to that.

NATURAL REGENERATION OF UPLAND HARDWOODS IN THE UPPER MISSISSIPPI VALLEY

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ABSTRACT

For regeneration purposes, three types of forest stands can be considered for the Upper Mississippi Valley region: (1) sugar maple-basswood, (2) oak, and (3) degraded hardwood. Sugar maple-basswood stands can be regenerated by the selection method, the two-cut shelter-wood method, or the clearcut method. In both the shelterwood and clear-cut methods, successful regeneration of sugar maple will require at least 5,000 stems per acre (12,355/ha) of advance reproduction from 2- to 4- feet (0.6 to 1.2 m) tall before making the final harvest cut. Oaks should be regenerated using the even-aged methods of clearcutting or shelterwood cutting. In either method, at least 430 well-distributed stems per acre (1,063/ha) of advance oak reproduction 4.5 ft (1.4 m) tall or taller should be present before final harvest cutting. However, expected numbers of oak stump sprouts can be used to compensate for deficiencies in advance oak reproduction. Degraded hardwood stands dominated by commercially undesirable species may require artificial regeneration by planting accompanied by intensive site preparation.

ANNOTATION

Methods are described for regenerating three types of forest stands in the Upper Mississippi Valley region: sugar maple-basswood, oak, and degraded hardwood.

KEY WORDS

Selection method, shelterwood method, clearcut method, Acer saccharum Marsh., Tilia americana L., Quercus rubra L., Fraxinus americana L.

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For the purpose of this paper, forests of the Upper Mississippi Valley will be defined as those occurring in the adjacent four-State region of southwestern Wisconsin, southeastern Minnesota, northeastern Iowa, and northwestern Illinois. This area is contiguous to the Mississippi River and lies mostly within what has been described as the "driftless area" (Braun, 1967; Martin, 1965). The region contains more than 3 million acres of upland forest with about two thirds of this acreage lying within southwestern Wisconsin (Stone and Thorne, 1961; Stone, 1966; Thornton and Morgan, 1959; Essex and Gansner, 1965).

CHARACTERISTICS OF THE UPLAND FOREST

This region is bordered by the northern hardwood region to the North and East, the oak-hickory region to the South, and the prairie province to the West. Because the region is phytogeographically transitional, it has silvicultural problems peculiar to both more southerly and more northerly forests, as well as some problems not common to either of the other forest zones. Although Braun (1967) considers the area to lie largely within the maple-basswood (Acer-Tilia) forest region, many of the existing forests in the region are dominated by oaks (Quercus spp.).

Curtis (1959) described the upland forests of southern Wisconsin as gradational from xerophytic to mesophytic depending on the proportion of mesophytic species present. He described the oak-dominated xeric or dry forests as unstable with the dominance of any one species likely to last only one generation. In contrast, he described the mesic forests of sugar maple (Acer saccharum Marsh.) and American basswood (Tilia americana L.) as stable assemblages of species potentially capable of reproducing in their own shade. Catastrophe, Curtis suggested, is the mechanism by which oak species are maintained in either xeric or mesic communities. Such catastrophic events include both man-made and natural phenomena including burning, grazing, windthrow, insect and disease outbreaks, and timber harvesting.

Marks (1942) attributed the origin of much of the region's oak forests to recurrent fires set by Indians during the 100-year period that ended with the arrival of European settlers in the mid-eighteen hundreds. Fires apparently eliminated or prevented extensive development of much of the fire sensitive sugar maple forests. With the cessation of burning, areas described as "scrub" by the early surveyors quickly developed into the dense oak stands present today. And many of these stands still do not contain sugar maple or American basswood in either the overstory or understory.

However, some oak stands do contain sugar maple and other tolerant species and where seed sources of these tolerants are adequate, reproduction of these species may develop in the understories of the oak stands. When timber harvesting or other disturbances release these tolerant understories, they quickly replace the less tolerant oaks.

Soils, Topography, and Site Quality

Upland soils of the region are predominantly loessal. Except on steep slopes, these silty soils are typically deep, rock free, and do not possess a significant pan layer (Kittleson and Dideriksen, 1968; Slota, 1969). Most of these well-drained soils are now included in the Hapludalf suborder of the Alfisol soils order (USDA Soil Conservation Service, 1975). Formerly, they were classified as Gray-Brown Podzolic and at times referred to as prairie-forest soils and grood loams (Wilde et al., 1949). Other common soils in the region include sandy loams formed in sandstone residuum (Langton, 1977) and soils formed in alluvial sands. The latter are primarily restricted to alluvial floodplains forming broad valleys of the larger river systems.

Einspahr and McComb (1951) found that for a wide range of upland soils in northeastern Iowa, the site index of oak and mixed oak stands ranged from 33 to 64 ft (10.1 to 19.5 m) based on Schnur's (1937) curves. They pointed out a strong positive relation between soil (solum) thickness and site index; in addition, they found that slope percent and aspect also significantly influenced site index.

Regeneration Problems

For the purpose of discussing regeneration problems, we will consider three major upland forest types of the region: (1) sugar maple-basswood, which may include as major components northern red oak (Quercus rubra L.), white ash (Fraxinus americana L.), and other mesophytes; (2) predominantly oak, which we divided into xeric and mesic subtypes; and (3) degraded hardwood which have largely resulted from the combined effects of timber harvesting and natural succession in oak types.

REGENERATING SUGAR MAPLE-BASSWOOD FORESTS

Sugar maple-basswood forests are the most mesic and potentially the most diverse, stable, and ecologically complex forests of the region. They occur in various stages of successional development ranging from nearly pure sugar maple-basswood forests to forests containing various quantities of northern red oak, red maple (Acer rubrum L.), white ash, eastern hophornbeam (Ostrya virginiana (Mill.) K. Koch), bitternut hickory (Carya cordiformis (Wang.) K. Koch), slippery elm (Ulmus rubra L.), and other mesophytes. Forest cover types include Sugar Maple (Type 27) and Sugar Maple-Basswood (Type 26) (Eyre, 1980).

Silviculturally, these forests are both easy and difficult to manage: easy because with appropriate silvicultural methods they can be consistently regenerated to sugar maple but difficult because regenerating less tolerant species often fails. For example, red oak reproduction in maple-basswood stands usually fails to develop even though it may be abundant.

Regeneration Characteristics of Major Species

Sugar maple. Sugar maple reproduction is seldom difficult to obtain where seed sources are adequate. In mature sugar maple stands, some seed is produced every year, even though large seed crops only occur at intervals from 2 to 5 years (Godman, 1965). In southern Wisconsin, annual production of viable seeds per acre ranged from about 1,200 to more than 2½ million (2,164 to 6.2 million/ha) (Curtis, 1959). Despite these fluctuations, understory populations of small seedlings that survive their first year remain constant (Hett, 1971). Consequently, thousands of seedlings per acre of advance reproduction, mostly less than 1 foot (0.3 m) tall, are present under stands of seed-bearing age. Variability in overstory density, ranging from 30 to 90 square feet of basal area per acre (6.9 to 20.7 m^2/ha), had no significant effect on the number of seedlings per acre 5 years after thinning (Church, 1960).

The great shade tolerance of sugar maple reproduction combined with its abundance makes it perhaps the easiest species to regenerate naturally wherever it is present in the overstory. The primary silvicultural problem is obtaining adequate size development of reproduction, and as discussed later, silvicultural methods have been developed for solving that problem.

Sugar maple's absence over extensive areas in the region may be linked to its lack of fire resistance and the long history of burning that predated the settlement period of the 1860's (Marks, 1942). Its thin bark is easily damaged by ground fires, and cambial injury can occur even in trees that don't show external charring (Curtis, 1959). Also, mature fire-killed trees seldom sprout, unlike mature oaks and American basswood that may sprout prolifically following burning.

American basswood. American basswood is the second-most important species of the mesic hardwood forests of the region (Curtis 1959). But despite its shade tolerance, American basswood reproduction is scarce in most stands even where it is a major overstory component (Godman, 1965; Godman and Mattson, 1976). An important barrier to establishment of basswood reproduction is the uncertainty of seed germination even though good seed crops may be produced almost every year (Godman and Mattson, 1976). Seed germination may be delayed for up to 4 years because of seed coat impermeability and embryo dormancy (Scholz, 1965). And rabbits often severely damage the few basswood seedlings that do become established (Scholz, 1965).

As a consequence, silvicultural opportunities for regenerating basswood are largely predetermined by the presence of overstory trees that can produce sprouts. In this capacity, few hardwoods surpass American basswood. Whereas presettlement fires nearly eliminated sugar maple and other hardwoods from extensive areas in southeastern Minnesota, American basswood became abundant because of its sprouting ability (Daubenmire, 1936).

White ash. White ash is one of the more economically valuable components of the region's maple-basswood forests. Curtis (1959) found that it occurred in about one-half of the undisturbed mesic stands in his ecological studies in

southern Wisconsin, although it was usually a minor component. Curtis assigned a climax adaptation number of 6.5 to white ash; this represents on a scale of 1 (bur oak (Quercus macrocarpa Michx.)) to 10 (sugar maple) an intermediate ranking in its adaptability to the climax sugar maple forests of southern Wisconsin. Despite its potential silvicultural importance, little is known about regenerating white ash.

Apparently the irregular flowering and seeding habits of white ash are an important cause of its poor representation in most stands. White ash is dioecious and although male trees may flower prolifically every year, female trees flower only 2 or 3 years out of 5 (Wright, 1965). And Bjorkbom (1979) observed no seed production during a 6-year period in the Allegheny region. Although seed is dispersed up to 450 feet (137 m) (Cope 1948), wind-borne pollen travels only about half that distance (Wright 1965). Wright (1965) thus suggested that in view of the low percentage of trees that seed abundantly and the limited dispersal distances for pollen and seed, obtaining adequate stocking of reproduction will require from four to six seed-producing trees per acre (10 to 15/ha).

Higher proportions of seed germinate the second year after seedfall than the first year; and some germination will continue from 3 to 5 years after seedfall (Marquis, 1975). Abundant advance reproduction of white ash is necessary for its successful regeneration in the Allegheny Plateau (Marquis et al., 1975); there it develops best under sawtimber stands with 40 to 60 ft^2 per acre (9.2 to 13.8 m^2/ha) of basal area (Leak and Solomon, 1975). Although reproduction is shade tolerant, it develops slowly under closed canopies (Cope, 1948).

As white ash gets older, it becomes less shade tolerant and has been ranked as intermediate (Wright, 1965). The species' moderate intolerance thus indicates its suitability for regeneration under an even-aged silvicultural system. The rapid height growth of white ash has been demonstrated by trees planted in a southern Wisconsin clearcut; about one-third attained codominant or larger status after 16 years and these averaged 3.1 inches (7.9 cm) d.b.h. (Johnson and Rogers, 198_).

White ash also sprouts readily from cut seedlings as well as from larger stumps. However, white ash stump sprouts in Connecticut had fewer stems per clump and grew slower than associated oaks (Schwarz, 1907).

Northern red oak. Northern red oak is often an important component of maple-basswood forests. Based on its average "importance value" in mesic southern Wisconsin stands (Curtis 1959), it ranked fifth among all tree species, and occurred in about 55 percent of the stands studied. Unfortunately, red oaks seldom successfully regenerate in these stands, apparently because of the low light intensities and dense sugar maple reproduction under mesophytic crown canopies. The occurrence of red oak in such stands is apparently related to disturbances that permit its entry into these mesic forests.

In a southwestern Wisconsin stand dominated by sugar maple and red oak, the red oak had originated 60 to 100 years after many of the uneven-aged overstory

maples (Lorimer, 198_). Most of the ultimately successful oaks had developed in canopy gaps that averaged about 45 ft (13.8 m) in diameter. These gaps originated from a disturbance (possibly a heavy partial cut) about 1897. The oaks did not germinate after the disturbance but were present before that event. Fire was ruled out as a probable cause of the disturbance because any fire hot enough to kill the overstory trees also would have killed the maples.

Populations of northern red oak seedlings in maple-basswood forests of the region fluctuate greatly and range from none to more than 7,000 per acre (17,297/ha) (Johnson, 1974; Scholz, 1955a). Peak populations originate from bumper acorn crops, which occur only about 1 year in four or five. However, these seedling populations decline to extinction rapidly with the dropout rate partially dependent on the nature of the ground cover (fig. 1). To successfully regenerate oaks, an adequate number of well-developed advance reproduction stems must be present before removing the overstory. About 430 well-distributed oak stems per acre (1,063/ha) at least 4.5 ft (1.4 m) tall are necessary to reasonably assure complete site utilization by oaks in the future stand at age 30 (Sander, et al. 1976). However, these population densities seldom occur in mesic forests.

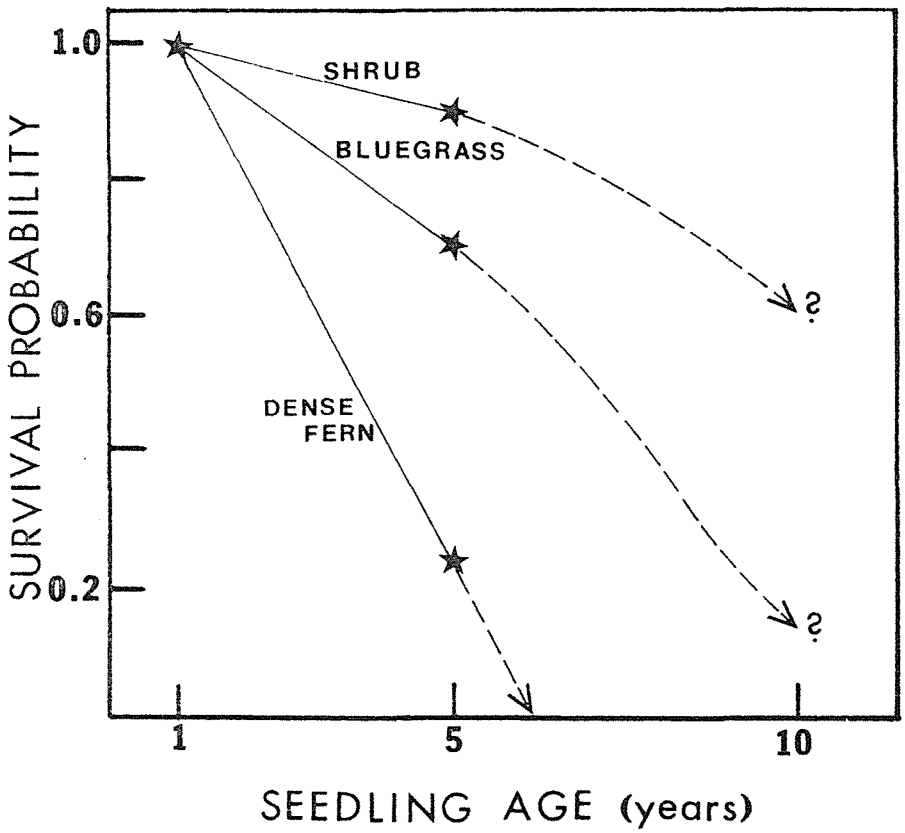

Figure 1.--Survival probabilities for northern red oak advance reproduction under three ground cover types in southwestern Wisconsin (stars are observed values). (Adapted from Scholz, 1955b.)

Obtaining adequate growth of oak reproduction after complete overstory removal requires reproduction with large root systems that can support rapid shoot elongation. Shoot elongation in oaks is periodic, i.e., it occurs in distinct flushes separated by periods of resting. Mature oaks only flush once per year, whereas juvenile oaks have the potential to flush several times (Borchert, 1976; Buech, 1976). But multiple flushing in small oak seedlings occurs only under the most favorable conditions of light and soil moisture--such as a well-watered nursery bed. The probability of obtaining multiple flushing or long single flushes under field conditions is negligible until the seedling builds a large root system with a high root:shoot ratio (Johnson, 1979).

Under field conditions, root mass and root:shoot ratio increase when plant water stress causes recurrent shoot dieback and the development of "seedling-sprouts"; this growth form may have roots many years older than shoots (Liming and Johnston, 1944; Merz and Boyce, 1956). Recurrent shoot dieback may continue for decades if light intensities are adequate. However, under the low light intensities of a mesic forest understory, large roots with high root:shoot ratios are seldom attained before the seedling-sprout dies. Nevertheless, a fortuitous combination of high seedling population density combined with a year or two of favorable soil moisture followed by overstory removal or destruction may explain the occassional "successes" of red oak reproduction in mesophytic forests. Fire may also favor oak development by reducing or eliminating more fire-sensitive competitors (Carvell, 1979).

Silvicultural Methods for Regenerating Maple-Basswood Forests

Three silvicultural methods can be used to regenerate sugar maple-basswood forests: (1) selection--either single-tree or group, (2) shelterwood, and (3) clearcutting. The seed tree method is not considered a good choice where, as in the sugar maple-basswood type, the new stand must originate from reproduction established before harvest cutting (Nyland *et al.*, 1981).

The selection method. The objective of this method is to create or maintain an uneven-aged forest. This is accomplished by light to moderate tree removals at 10- to 20-year intervals. In the single-tree selection method, individual trees are removed to make space for small seedlings to develop in the gaps created. The method will satisfy the regeneration requirements of only the most tolerant species. Consequently, in the Upper Mississippi Valley, the method should be applied only to those stands where regenerating sugar maple is feasible.

The recommended residual basal area after cutting is 70 ft^2 per acre (16.1 to 18.4 m^2/ha) in trees 10 inches (25 cm) d.b.h. and larger (Tubbs 1977). However, no more than about 40 ft^2 per acre (9.2 m^2/ha) should be removed in a single cutting (Leak *et al.*, 1969). The residual basal area should be distributed over all diameter classes so that the exponential distribution of diameters is negative after cutting (i.e., the plot of the logarithm of stem number over d.b.h. should approximate a straight line) (Leak, 1978). In previously unmanaged stands, several cuttings at 10- to 20-year intervals may

be needed to achieve the desired diameter distribution (table 1). In making selection cuts, it is important to make the removals across all diameter classes that have stems in excess of stocking needs. All too often a "diameter limit" cut is substituted for the judicious selection of stems based on diameter distribution criteria; this results in "selectively cut" and mismanaged stands and not selection cuttings.

Table 1. Desirable distribution of basal area and numbers of trees per acre using the selection method 1/

D.b.h. Class	Average number of trees per acre	Basal area per acre
(Inches)	(Number)	(ft^2)
2-4	202	8
5-9	65	16
10-14	28	22
15-19	17	26
20+	8	20

1/ From Tubbs, 1977.

A problem in applying the selection method in some stands of the region is the development of undesirable species in the lower crown strata. Prominent species in this category include slippery elm, bitternut hickory, and eastern hophornbeam. Where these species are abundant, selection cuttings may encourage their movement into the main canopy. If this is unacceptable, the manager can examine the possibilities of even-aged management. For example, a single shelterwood cutting could be used to eliminate an undesirable lower strata, while leaving the main canopy of desirable species intact.

The group selection method is a variant of the selection method in which trees are removed in small groups. Group size is generally less than 0.2 acre (0.08 ha). Group removals of 0.1 acre (0.04 ha) or less may provide adequate space for the development of northern red oak reproduction (Lorimer, 198_). However, the advance red oak should be well-developed before group removals are made because small oak advance reproduction has little or no chance of development after cutting. For oaks, stems of advance reproduction should be at least 4.5 ft (1.4 m) tall and number at least 43 per 0.1 acre (0.04 ha) wherever the group selection removals will be made (Sander et al., 1976). Similar guidelines for white ash and other desirable species have not been

developed for the region. Nevertheless, any reproduction suppressed by other reproduction or understory vegetation is not likely to contribute to future stand stocking.

Selection methods may be attractive to many small private landowners because the forest is never completely cut and the aesthetic appeal of a mature forest is maintained. The system also provides good watershed protection. Although wildlife habitat will be temporarily improved following cuttings, benefits will last only until tree crowns grow into the new canopy gaps (Nyland et al., 1981). The system's major disadvantage is that it is well-adapted to regenerating only one economically important species, sugar maple.

The shelterwood method. The two-cut shelterwood method has proven to be reliable for establishing even-aged northern hardwoods in the northern part of the Lake States (Godman and Tubbs, 1973). Thus, we might also expect this method to work satisfactorily in the sugar maple-basswood forests of the Upper Mississippi Valley.

Two types of two-cut shelterwoods have been formulated; which one to use depends on whether or not desirable advance regeneration is present (Godman, 1979). Where desirable advance reproduction is present but not well-developed, stands should be reduced to 60 percent crown cover in the first cut by cutting from below. This cutting should be done when the ground is covered by snow to minimize seedbed disturbance and damage to advance reproduction. The overstory can then be removed when there are at least 5,000 stems per acre (12,355/ha) 2 to 4 ft (0.6 to 1.2 m) tall (Jacobs, 1974); this will usually take from 3 to 8 years. As in the first cutting, the removal cut should be done when the ground is snow covered, and all stems 2 inches (5.1 cm) d.b.h. and larger should be removed.

A modification of this system is recommended where no advance reproduction exists or no specific species such as white ash is present but desired. In this situation, the first cut should only reduce the crown cover to 70 to 80 percent. The higher residual overstory crown cover is used to prevent surface soil drying and to restrict herbaceous competition while the reproduction is becoming established. The first removal can be made in any season except summer. Summer logging introduces the risk of sapstreak disease resulting from root injury to overstory maples--which can kill trees (Hepting, 1971). As in the other type of shelterwood, the removal cut should be done when the ground is snow covered.

In both types of shelterwoods, thinning should be based on percent residual crown cover rather than residual basal area. Basal area is not a consistently good measure of crown cover because the basal area/crown cover relation differs among species. For example, a given diameter of sugar maple has less basal area per unit crown area than basswood does (Godman and Tubbs, 1973). In any case, the residual crown should be evenly spaced--even if this requires leaving some undesirable species. A seed source of at least four well-distributed trees of seedbearing age of preferred species should occupy each acre of the shelterwood. Stands should also average at least 8 inches (20.3 cm) d.b.h. Additional details on using the system in northern hardwoods are available (Godman and Tubbs, 1973; Godman, 1979; Jacobs, 1974).

Although the shelterwood method is potentially workable for regenerating oaks (Sander, 1979), it is unlikely to succeed where sugar maple advance reproduction is present. Newly established oaks will not be able to compete with the maple reproduction, particularly if the maples respond favorably to the reduced crown cover provided by the first shelterwood cutting. However, if the overstory oaks are not too old, a small oak component may be perpetuated by stump sprouting (Johnson, 1975).

Advantages of the shelterwood method include: (1) the assurance that adequate regeneration is in place before the overstory (seed source) is removed, (2) the average rotation length is shortened because one rotation is "telescoped" into another (Smith, 1979), (3) the brushy and aesthetically unattractive stage of early stand development is minimized because reproduction is well-developed before the overstory is removed, (4) protection of sensitive species, including sugar maple and white ash, from "exposure" during critical establishment periods, and (5) easy removal of undesirable species in the lower crown strata because thinning is from below. Although the need to harvest the overstory when advance reproduction is present is sometimes cited as a disadvantage of the shelterwood system, damage is generally inconsequential if regeneration is well-distributed, well-developed, and present in adequate numbers (Jacobs, 1974).

Disadvantages of the shelterwood method in maple-basswood stands are: (1) it has not been proven by field trials within the region, and (2) except for small numbers of stump sprouts, it is unlikely to successfully regenerate oaks even when oak seed sources are present.

The clearcut method. Clearcutting can be successfully applied in maple-basswood forests wherever number, size, and distribution of advance reproduction of desirable species is adequate. Use the same criteria for evaluating regeneration adequacy as you would in the shelterwood method. Then, if advance regeneration of desirable species is adequate, the stand can be clearcut; it is generally recommended that all stems down to 2 inches (5.1 cm) d.b.h. be cut (Leak et al., 1969; Roach and Gingrich, 1968). Clearcutting without adequate advance reproduction is usually unsuccessful (Metzger and Tubbs, 1971; Metzger, 1980) and the two-cut shelterwood method should be used instead (if an even-aged stand is desired).

Advantages of clearcutting include: (1) immediate realization of the cash value of the standing crop, (2) excellent habitat for wildlife during the first 10 to 15 years of stand development, (3) high light conditions necessary for the growth of valuable intolerant species, and (4) increased water yields during the first decade after cutting. Disadvantages include an unattractive appearance of the clearcut area for a few years, and in some cases large numbers of stump sprouts of undesirable species that may compete with more valuable reproduction. However, the latter problem can be eliminated by applying an appropriate herbicide to cut stumps.

REGENERATING OAK FORESTS

The oak forests of the region comprise a diversity of communities that occupy xeric to mesic sites and a correspondingly wide range of oak site indices from about 40 to 70 ft (12.2 to 21.3 m). The drier sites are usually dominated by some combination of white oak (Quercus alba L.), black oak (Q. velutina Lam.), and bur oak, although northern red oak and northern pin oak (Q. ellipsoidalis E. J. Hill) may also be present. Important non-oak associates include black cherry (Prunus serotina Ehrh.), shagbark hickory (Carya ovata (Mill.) K. Koch), and American elm (Ulmus americana L.) (Curtis, 1959). The more mesic sites are usually dominated by northern red oak, and total stand basal areas may exceed 150 ft^2 per acre (34.5 m^2/ha) (Gevorkiantz and Scholz, 1948). Important associates of red oak in mesic oak forests include white oak, American basswood, sugar maple, slippery elm, white ash, eastern hophornbeam, black cherry, and shagbark hickory. Oak cover types (Eyre 1980) that occur in the region include: bur oak (type 42), white oak-black oak-northern red oak (type 52), white oak (type 53), black oak (type 110), northern red oak (type 55), and northern pin oak (type 14).

A conspicuous feature of the region's oak forests is the dense shrub layer. Prevalent shrubs include gray dogwood (Cornus racemosa Lam.), blackberry (Rubus allegheniensis Porter), raspberry (Rubus idaeus L.), American hazelnut (Corylus americana Walt.), and gooseberry (Ribes cynosbati L.). Ferns may also form a dense groundlayer especially on north- and east-facing slopes; prevalent species are lady fern (Athyrium felix-femina L.) and interrupted fern (Osmunda claytonia L.). Both the shrub layer and the groundlayer are important silviculturally because they can impede the development of oak and other desirable tree reproduction.

Regeneration Characteristics of Oak Forests

Dry and dry-mesic oak forests. Oak seedling reproduction is well adapted to survival under high water stress, but to do so it requires moderately high light intensities and a long developmental period. Favorable light conditions occur most frequently on the drier sites where water stress limits overstory density and restricts shrub layer development. Under these conditions, the root mass of seedling-sprouts can continue to increase even though shoots recurrently die back. Consequently, several decades may be required before a substantial amount of oak reproduction with large root systems capable of supporting rapid shoot elongation can develop. This buildup of oak advance reproduction begins with the natural opening-up of crown canopies as stands approach maturity--typically occurring after 60 years of age.

However, not all oak species are equally adapted to survival and development under water stress. Black oak and bur oak are among the more xerophytic oaks, possessing a thick leaf cuticle that minimizes water loss when stomates are closed. These two species also have higher water use efficiencies than red oak and white oak, i.e., they can take up large amounts of carbon dioxide while minimizing the amount of water they lose in transpiration (Wuenscher and Kozlowski, 1971). Thus black oak and bur oak frequently occur as the dominant species on the driest sites in the region. Stands of these species occupy

deep sands, eroded ridge tops, and steep south- and west-facing slopes with thin soils. Oak regeneration is seldom a problem on such sites because ecological conditions favor the development of oak reproduction and limit the establishment of the more moisture demanding and shade tolerant species as well as a dense shrub or fern layer. These sites include those that fall below site index 50 ft (16.8 m) for red oak (Gevorkiantz, 1957).

Dry-mesic forests lie between xeric and mesic extremes and occupy sites in the red oak site index range of about 50 to 60 ft (15.2 to 18.3 m). These forests occupy soils ranging from sandy loams to silt loams of medium depth (20 to 30 inches (51 to 76 cm)) on level topography; on steep slopes, both soil depth and aspect limit site quality. Dry-mesic sites are average for the region and thus account for much of the region's upland forest resource.

Studies of tree-shrub relationships in the region have shown that maximum shrub densities occur in dry-mesic oak forests (Loucks and Schnur, 1976). These forests are often dominated by a mixture of black, white, and northern red oaks (Curtis, 1959). In these stands, density of all tree reproduction tends to be inversely proportional to shrub density (Loucks and Schnur, 1976). Furthermore, shrub densities increase as overstory densities decrease. Thus thinning in these stands usually results in releasing shrub understories and depressing total tree seedling populations. This relationship has been further supported by a study that showed that after clearcutting, maximum tree reproduction of all species combined occurred where overstory density of the parent stand was highest (Johnson, 1976).

Both overstory removals and successional processes tend to displace oaks as dominants on dry-mesic sites. Oaks are most frequently replaced by black cherry and shagbark hickory--a phenomenon causing the widespread emergence of a new and stable cherry-hickory complex (Peet and Loucks, 1977; Johnson, 1976). In addition to being commercially inferior to the oak forests that preceded them, the new forests have lower overstory densities and even higher shrub densities than their predecessors.

Black cherry in this region seldom attains commercial value because of serious bole degrade caused by black knot fungus (Dibotryon morbosum). Nevertheless, on many oak sites, black cherry emerges as the predominant species following clearcutting (Johnson, 1976). The ecological success of this species in southern Wisconsin forests has been attributed to its widespread seed dispersal, delayed germination, and flexible seedbed requirements (Auclair and Cottam, 1971).

Mesic oak forests. Mesic oak forests are usually dominated by northern red oak with white oak the most common associate (Curtis, 1959). These forests typically occupy north- and east-facing slopes but also may be found on nearly level areas with deep silt loam soils. Site indices for red oak exceed 60 ft (18.3 m). In forests where several sugar maples of seed-bearing age are present per acre, sugar maple reproduction is likely to be abundant and succession will be toward that species.

Because stand basal areas can exceed 150 ft^2 per acre (34.5 m^2/ha) crown canopies of these forests are dense; accordingly, the shrub layer is less

well-developed than in dry-mesic oak forests. Nevertheless, when overstory density is reduced, the shrub layer may quickly respond. In the most mesic microsites, dense fern cover may replace the shrub layer. Oak regeneration on these sites consequently possesses problems and characteristics of both the dry-mesic oak and mesic sugar maple-basswood forests. Regenerating red oak on these sites is one of the most intractable problems in hardwood silviculture.

Where both red oak and sugar maple advance reproduction is absent or inadequately developed, stands often regenerate predominantly to slippery and American elms, bitternut hickory, and eastern hophornbeam after overstory removal. Oak stands on both mesic and dry-mesic sites may also convert to aspen (Populus spp.) where these species are present in the parent stand. Reproduction of aspens originates mainly from root suckers.

Silvicultural Methods for Regenerating Oak Forests

Two silvicultural methods can be considered for regenerating oak forests: (1) clearcut, and (2) shelterwood. In applying either method, the recommendations are essentially the same as for regenerating sugar maple-basswood forests, i.e., advance reproduction of the desired species must be present in adequate numbers, size, and spatial distribution before making the final overstory removal cut. The selection cutting method cannot be used to regenerate oaks because of their intolerance to shade. The seed tree method is also of no value because it is designed to provide a seed source after the major part of the stand has been removed.

The clearcut method. The clearcut method is the simplest and least costly of the two methods to apply. However, it should only be used where adequate advance reproduction of oaks or other desirable species are present. Adequate oak reproduction is defined as a minimum of 430 well-distributed oaks per acre (1,063/ha) at least 4.5 ft (1.4 m) tall. A guide for evaluating the adequacy of oak advance reproduction is available (Sander et al., 1976).

Oak stump sprouts that will develop after clearcutting can be used to compensate for deficiencies in advance reproduction. Numbers of these stumps expected to sprout can be estimated using the advance reproduction guide and a tally of the diameter distribution of oaks in the parent stand (fig. 2). If basswood is present, it can be assumed that all of them that are cut will sprout. Reproduction from stump sprouts of oaks and basswood is generally acceptable, even though there is some risk of decay entry from the parent stump. However, this risk can be minimized by cutting stumps low (Roth and Hepting, 1969) and by early clump thinning (Johnson and Rogers, 1980; Butin and Shigo, 1981).

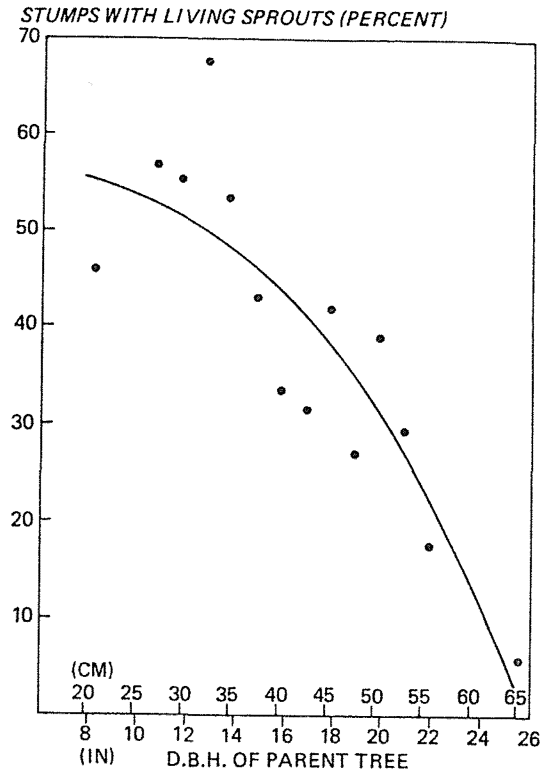

Figure 2.--Relation between percent of northern red oak stumps with living sprouts and d.b.h. of the parent tree (ages 85 to 115) in southern Wisconsin (from Johnson, 1975).

Red oak and basswood stump sprouts grow rapidly and both species retain large numbers of stems per clump to age 30 and beyond if not thinned. To maximize growth and quality of individual red oak sprout stems, clumps should be thinned to one stem as early as possible, preferably before age 15 (Johnson and Rogers, 1980).

Although it is generally recommended that adequate advance oak reproduction be present before clearcutting, a recently documented case history (Johnson and Jacobs, 1981) has suggested an alternative: apply a herbicide in late summer just before a good acorn crop to control understory vegetation and then clearcut the stand the following winter. A single trial in a 6-acre (2.4 ha) red oak stand in southwestern Wisconsin has resulted in about 2,800 northern red oak seedlings per acre (6,916/ha) 5 years after cutting; about 300 of these were well-distributed and codominant or larger. Although we know little about this method, its apparent initial success may cause us to reconsider the assumption that it is always necessary to obtain red oak reproduction in advance of the final cut. Even so, a primary disadvantage of this method is that regeneration success cannot be determined until after the seed source (parent stand) has been removed. A safer approach is the shelterwood method.

The shelterwood method. The shelterwood method has seldom been applied to oak forests despite the logic of its use. Although research on applying it in

oak stands is underway in several regions, no definitive prescriptions for using it have been developed. Nevertheless, we have two documented case histories of shelterwood cutting in mesic red oak stands in southwestern Wisconsin that have produced encouraging results (Johnson and Jacobs, 1981). These trials have indicated that reducing the stand basal area to about 60 ft^2 per acre (13.8 m^2/ha) in one or two preparatory cuts can result in stands with moderately good stocking of red oak reproduction after the final removal cut. In these stands, a single or a secondary preparatory cut was made from 6 to 9 years before the removal cut. Within 11 years after the final removal cuts, from 180 to 200 well-distributed red oaks per acre (445 to 494/ha) originating from advance reproduction were codominant or larger in both stands. This contrasts with the 25 or fewer red oaks per acre (62/ha) we could expect at the same ages after applying the clearcut method (Johnson, 1976). The encouraging results from these case studies suggest that even greater success might be obtained by combining shelterwood cuts with understory control using herbicides. However, coordinating herbicide applications with bumper acorn crops may be necessary to assure success.

Prescribed burning has frequently been suggested as a way to regenerate oaks because of the historical relation between fire and the apparent origin of the region's oak forests (Marks, 1942). However, a single prescribed spring burn in a mesic red oak stand reduced the population of 1-year-old understory oak seedlings by 58 percent and failed to reduce competition (Johnson, 1974). Additional research is needed to determine under what stand and site conditions prescribed burning might control competing vegetation and at the same time favor the establishment and growth of oak reproduction.

REGENERATING DEGRADED HARDWOOD TYPES

Regenerating degraded stands to oaks and other more economically valuable species by relying on natural regeneration will be impossible if seed sources of desirable species have been eliminated. In such cases, site preparation using herbicides and artificial regeneration by planting may be the best solution. Such stands can be clearcut, herbicided, and successfully planted with white ash and sugar maple (Johnson and Rogers, 198_). Another option that may be more suitable for establishing oaks would be to herbicide the understory, underplant, and after several years remove the overstory when the underplanted trees have become well-established (Johnson and Rogers, 198_).

Even when seed-bearing trees of valuable species are present in these stands, dense shrub understories may inhibit seedling development. Although research and practical experience is lacking, such stands might be successfully regenerated naturally after herbiciding the shrub layer. However, this would probably only work for light-seeded species such as sugar maple and white ash.

SUMMARY

Silvicultural methods used to regenerate upland hardwoods in the Upper Mississippi Valley should be based on the site conditions and on the composition, structure, and successional stage of the stands. For the region, three broad classes of forest types can be considered: (1) sugar maple-basswood (2) oak, and (3) degraded hardwood.

On mesic sites, sugar maple-basswood forests are climax. Succession proceeds rapidly toward dominance by sugar maple on good sites wherever seed-bearing trees of this species are present. These stands will be easy to regenerate to sugar maple by the selection method--either single-tree or group. This is the only upland type within the region suited to management by the selection method. Sugar maple-basswood forests can also be regenerated by the two-cut shelterwood method, which allows reproduction to develop to 2 to 4 ft (0.5 to 1.2 m) in height under 60 percent crown cover before making the removal cut. These forests can also be regenerated using the clearcut method provided advance reproduction of desirable species is already in place and well-developed.

The primary problem in regenerating sugar maple-basswood stands using any of the above methods is the difficulty in obtaining much reproduction of desirable species other than sugar maple. A northern red oak component originating from seedlings and seedling sprouts is extremely difficult to maintain in these stands because of this species' relative intolerance to shade. Most red oak and basswood reproduction will originate from stump sprouts.

Oak stands should be regenerated using the even-aged methods of clearcutting or shelterwood cutting. On the driest sites (site indices below 50 ft (15.2 m)), clearcutting is the simplest and most effective method provided that at least 430 well-distributed stems of advance oak reproduction 4.5 ft (1.4 m) tall or taller are present. However, oak stump sprouts are also an acceptable source of reproduction. Expected numbers of stump sprouts can be estimated from available guidelines and a tally of overstory tree diameters. These estimates can then be used to partially offset advance reproduction needs. Where oak reproduction is still judged inadequate, the shelterwood method is preferred.

On oak sites above site index 60 (18.2 m), adequate oak advance reproduction is usually lacking. The shelterwood method has shown some promise for increasing oak advance reproduction of adequate size. In applying the shelterwood system, basal area should be reduced to about 60 ft^2 per acre (13.8 m^2/ha). When oak advance reproduction is adequately developed and distributed, the overstory can be removed; this may take 10 years or longer.

A primary regeneration problem on these oak sites is the dense shrub layer that often becomes even more dense after shelterwood preparatory cuts--which may further depress establishment and development of oak reproduction. Herbiciding the shrub layer just prior to a good acorn crop may be one way to eliminate shrub competition and establish oak reproduction.

Stands dominated by black cherry, hickories, and other non-commercial species are the result of earlier removals of oaks and natural successional processes. These stands typically have low density, low quality overstories with high density shrub layers. Seed sources for oak and other desirable hardwood regeneration are often absent. Restoring these sites to their productive capacity will require intensive site preparation and artificial regeneration by planting.

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QUESTIONS AND DISCUSSION

Question: How long before the end of a rotation of a growth stand should attention be given to establishing advanced oak regeneration?

Answer: (Paul Johnson) Oh, at least a decade, at least 10 years.

Question: Does the time of the year that red oak is cut affect stump sprouting?

Answer: (Paul Johnson) There have been some studies that have indicated that there is some reduction in stump sprouting if the tree is cut during the period of rapid leaf expansion or shortly thereafter, which in this area would be during the month of May, perhaps early June. Cutting in that period of time might conceivably reduce the frequency of stump sprouting.

Question: When is it too late to remove one stem of a double stem sprout?

Answer: (Paul Johnson) Well, I'm not not sure that it is every too late per se. It depends on how the two stems are connected. As a matter of fact, if there is any kind of direct stem connection, I would suggest that it might be too late.

Question: What role do you see for fire as a regeneration treatment?

Answer: (Paul Johnson) The limitations in the use of fire are probably limited by social constraints. I think to the extent to which prescribed burning would ever be acceptable in a region such as this and I'm probably less qualified to answer that question than a lot of you people are. Maybe I ought to ask the question, "How many of you would perceive of using prescribed burning as a silvicultural tool as something that you could implement, if for example, we could give you information on how to use it to advantage? Could you use it and would you be willing to use?" I'd be interested in hearing some responses to that question. Two "yeses" and 148 -hahahahaha's.

NATURAL REGENERATION OF BOTTOMLAND HARDWOODS IN THE UPPER MISSISSIPPI RIVER VALLEY

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ABSTRACT - In the upper Mississippi Valley, high quality hardwood stands are found growing on a variety of sites. These stands range from simple aggregates such as cottonwood or willow to complex mixed associations consisting of numerous species. The composition reflects the varying tolerances and growth rates of the species that compose them. They may also show the influences of fires, flooding and other calamities. Successful regeneration to desirable species requires a complete understanding of the silvical needs of those species, and in most instances, advanced reproduction.

INTRODUCTION

In the Central States, the highest quality hardwoods are normally found growing along river and stream bottoms. The upper Mississippi River Valley north of Cairo, Illinois, is especially noted for producing trees of remarkable growth. Eastern cottonwood (Populus deltoides Bartr. var. deltoides) found growing from central Minnesota south has been reported to yield an average of 800 to 1,000 board feet per acre per year over the course of a rotation (Minckler, 1961). Mixed stands, though yielding less over a complete rotation, can produce as much as 1,800 board feet per acre per year over a span of two to three years following a thinning (Minckler, 1961). However, this potential can only be realized if sufficient stocking of desirable regeneration has been secured earlier in the rotation. The adequacy of regeneration depends upon a myriad of interacting biological and physical factors which often serve to limit the final composition of the stand.

Stand composition

Describing bottomland hardwood associations in the upper Mississippi Valley is difficult as there are many major forest types and many variations within each type. Putnam (1951) identified eight types in the bottomlands of the lower Mississippi River alone. The types in the upper valley vary from very simple aggregates such as cottonwood or willow to extremely complex mixed types consisting of numerous species, including silver maple (Acer saccarinum L.), red maple (Acer rubrum L.), American elm (Ulmus americana L.), green ash (Fraxinus pennsylvanica Marsh.), white ash (Fraxinus americana L.), sycamore (Platanus occidentalis L.), swamp white oak (Quercus bicolor Willd.). and others.

Changes in composition occur with sites and locations along the river. A study by Bryant (1963) in southern Michigan under conditions similar to those of the Mississippi River Valley, showed that the eight leading species in descending order of prominance were American elm, red maple, swamp white oak, green ash, silver maple, basswood (Tilia americana L.), cottonwood, and sugar maple (Acer saccharum Marsh.). American elm was the leading dominant in 35 percent of the stands surveyed. Red maple was dominant in 16 percent while green ash, swamp white oak, and sugar maple were leading dominants in

10 percent of the stands. Similar findings were also observed by Johnson in southern Michigan (1967 - unpublished data). In his work, which evaluated 27 separate stands, American elm and red-silver maple were present in each. American elm was the leading dominant in 14 stands; red-silver maple in 12. Collectively, these species accounted for 74 percent of the basal area observed in the 27 stands.

In a similar setting in southern Wisconsin, Ware (1955) studied the lowland forests and found that silver maple and American elm were the predominant species in 61 percent of the stands studied. Together with green ash, these three species were found to be the most important community group of the wetland forests.

Work reported by the Illinois Technical Forestry Association (1972) reveals that many of these same species are also prominant in the makeup of bottomland types in southern Illinois. In particular, green ash, American elm, silver maple, and cottonwood are reported to be common components of these forests. Minckler (1958) working within the Mississippi flood plain in southwestern Illinois found that silver maple, eastern cottonwood, green ash, and American elm made up about four-fifths of all the sawtimber-sized trees. Boxelder (Acer negundo L.) was prominant among the pole-sizes along with hackberry (Celtis occidentalis L.), sycamore, pecan (Carya illinoensis Koch), pin oak (Quercus palustris Muenchh.), and others.

While local demands may vary, eastern black walnut (Juglans nigra L.), green ash, silver maple, cottonwood, sycamore, bur oak (Quercus macrocarpa Michx.) and swamp white oak are classified as some of the more important timber species within the upper valley. Intermediate in importance are species such as hackberry, river birch (Betula nigra L.), and willow (Salix nigra Marsh.). American elm and boxelder, both prominant components of the area, are not normally identified as important timber types. Boxelder is classified as a weed species, while elm suffers severely from disease. Silvical and other characteristics of some of the more important timber species found within this area are given in Table 1. Present-day bottomland hardwood stands reflect the tolerance and the growth rates of the species that compose them and past stand treatment. One of the most serious problems may occur annually in the form of floods.

Response to flooding

Bottomland hardwood regeneration varies considerably in its ability to tolerate flooding conditions. Even within a species the response will vary depending upon the time of year flooding occurs, flood frequency, the duration of the flood, water depth, and even siltation. Many species can survive extended inundation during the dormant season and even brief inundation during the growing season. The tops of most seedlings, however, will be killed if flooded for more than two weeks after they have leafed out, although even here differences are observed between species (Broadfoot and Williston (1973). Species that leaf out later, such as green ash, have a much greater chance of surviving spring floods than species that characteristically leaf out early. Green ash is, however, susceptible to damage from total submersion following leafing out with survival decreasing to as little as 20 percent after 30 days (Hosner, 1960). To the contrary, some species such as boxelder,

TABLE 1. Some characteristics of important hardwood species in the Upper Mississippi River Valley.

Species	Shade Tolerance	Relative Growth Rate	Resistance to Fire Injury	Seedling Sprouting Ability	Importance as a Timber Species
Cottonwood	Intol.	Excel.	High	Low	High
Willow	Intol.	Excel.	Mod	Low	Mod
Sycamore	Intol.	Good to Excel.	Low	Low	High
Sweetgum	Intol.	Med. to Good	High	Mod	High
Silver Maple	Intermed.	Excel.	Low	Mod	Mod to Low
Red Maple	Intermed.	Med.	Low	Mod	Mod to Low
Sugar Maple	Tol.	Med.	Mod	Low	Mod to Low
Green Ash	Mod. Tol.	Med.	Mod	Mod	High
American Elm	Mod. Tol.	Med.	Mod	Mod	Mod to Low
Swamp White Oak	Intermed.	Med	High	High	High
Pin Oak	Intol.	Good to Excel.	Low	High	Mod to Low
Bur Oak	Intermed.	Med. to Poor	High	High	Mod
Black Walnut	Intol.	Med. to Good	Mod	Low	High

willow and silver maple have been found to be quite tolerant to flooding with no mortality observed after two weeks of complete inundation (Table 2).

Saturated soil conditions, while not as harmful as inundation, can adversely influence the growth of many species. Hackberry has been reported to be very sensitive to saturated soil conditions occurring during the growing season. Hosner (1960) found that after 10 days under saturated conditions, survival decreased to 6 percent; 100 percent mortality was observed after 20 days. Red maple has been shown to tolerate saturated conditions, but height growth is inhibited as is that of American elm (Hosner and Boyce, 1962). Silver maple, on the other hand, is even more tolerant and in contrast to red maple, height growth is enhanced (Hosner and Boyce, 1962).

Sedimentation can also harm or even kill seedlings. Areas close to the river may be especially affected during overflow periods due to the accumulation of sand and silt. While species such as cottonwood and willow can withstand moderate siltation, depths of several inches may accumulate during a flood. Unfortunately, three or more inches of this material may be sufficient to reduce the soil oxygen content within the root zone to a level below that required for seedling survival (Broadfoot and Williston, 1973).

Tolerance to shade

Throughout the upper Mississippi Valley type, most of the species that become established and thrive in the shade of other trees have little commercial value. The species of great value require direct sunlight for establishment and rapid growth. Regeneration of the most desirable species requires one-third to one-half full sunlight. Because of this, adequate advance reproduction of sufficient size and of desirable species seldom develops except in openings large enough to provide some direct sunlight for a substantial part of the day. Some species, such as pin oak will germinate and start growth under a heavy canopy, but the seedlings will die back to the root collar in two to three years unless they are released. Others such as green ash germinate plentifully and scattered individuals or groups of individuals may develop for several years in the partial light of small openings. Without overhead release, they disappear before reaching pole-size. Other species such as sweetgum (Liquidambar styraciflua L.) germinate sparsely in many stands and persist only briefly under a closed canopy. Species such as cottonwood, sycamore and willow, will tolerate little or no overhead cover. The more tolerant species, however, like hackberry, red maple, boxelder and American elm, grow poorly under shade, but do endure. Upon release, they may develop quickly, minimizing the chance for the growth of the more desirable intolerant types. However, if provided equal opportunities under open conditions, the intolerant species will outgrow the less desirable tolerant ones.

Hosner and Minckler (1960, 1963) demonstrated that many bottomland species in southern Illinois germinate and establish themselves best under relatively heavy canopies, but will disappear if not released. One- and two-year old seedlings of a number of species were found to be more abundant under canopies than in openings (Table 3).

TABLE 2. Seedling response to water level changes.

Species		Survival Under Inundation and Saturation	Comments
Acer negundo (boxelder)	A.l.	100% for 2 weeks, 70% for 3 weeks, 36% for 4 weeks (11).	Chlorotic leaves after 4 days, recovered slowly (6).
	A.l.	0% after 32 days (6).	
Acer rubrum (red maple)	B.l.	100% for 5 days, 90% for 10 days, 0% for 20 days (8).	Adventitious roots developed after 15 days (8).
	C.l.	100% after 32 days (13).	Seeds did not germinate under water (4). Height growth decreased in saturated soil (9).
Acer saccharinum (silver maple)	A.l.	100% after 3 weeks (11).	Wilted lower leaves after 2 days. Recovery slow (5).
	C.l.	100% after 60 days (8).	Flooding prevents seed germination. Good germination after flooding (4). Height growth better under saturated conditions than field capacity (8).
Betula nigra (river birch)	C.l.	100% for up to 32 days (12).	Severely stunted growth (12).
Celtis occidentalis (hackberry)	C.l.	100% after 30 days, 90% - 5 days, 6% - 10 days, 0% - 20 days (7).	Height growth worse in saturated soil than soil at field capacity (8).
Fraxinus pennsylvanica (green ash)	A.l.	100% after 5 days, 90% after 10 days, 73% after 20 days, 20% after 30 days (7).	Chlorotic lower leaves after 8 days (5). Better growth in saturated soil than soil at field capacity (7).
	B.l.	100% after 14 days (5).	
	C.l.	100% after 60 days (8).	Good germination in swampy areas (1,3).
Juglans nigra (black walnut)	A.l.	100% - 2 weeks, 60% - 3 weeks, 0% - 4 weeks (10).	
Platanus occidentalis (sycamore)	A.l.	100% after 10 days, 0% after 30 days (7).	Germination retarded by inundation (3).
	C.l.	95% after 32 days (8)	Growth decreased by saturated soil (12).

TABLE 2. Seedling response to water level changes, continued.

Populus deltoides (eastern cottonwood)	A.1. B.1.	0% after 16 days (5) 90% after 10 days, 70% after 20 days, 47% after 30 days (7, 8).	Seeds germinate quickly in water (4). Best height growth when water table is 2' below surface (1). Heavy mortality when deeply flooded (5).
Quercus palustris (pin oak)	A.1. C.1.	90% after 10 days 0% after 30 days (7). 100% after 60 days (8).	Poor growth in saturated soil (2). Winter flood detrimental to seedlings (13).
Salix nigra (black willow)	A.1. C.1.	100% after 30 days (5, 8). 100% after 60 days (8).	Height growth much better in saturated soil than at field capacity (8). Seed germinates in water (8).
Ulmus americana (American elm)	A.1. C.1.	100% after 10 days, 27% after 20 days 0% after 30 days (7). 100% after 15 days, 94% after 60 days (8, 12).	Decreased height growth in saturated soil (8).

Key: A - Total Submersion B - Partial Submersion C - Soil Saturation
1 - During growing season

Source: Teskey and Hinckley, 1978

References:
1. Broadfoot, 1973
2. Dickson, et al. 1965
3. DuBarry, 1963
4. Hosner, 1957
5. Hosner, 1958
6. Hosner, 1959
7. Hosner, 1960
8. Hosner and Boyce, 1962
9. Hunt, 1951
10. Loucks and Keen, 1973
11. McAlpine, 1961
12. McDermott, 1954
13. Minckler and McDermott, 1960

TABLE 3. Seedlings one to two years old by species and diameter of canopy openings, where h equals height of stand.

Species or Species Group	Diameter of Openings in Canopy 0	<½h	½h - 1h	>1h
Elm	384	493	358	205
Boxelder-hackberry	300	235	88	141
Silver maple	285	184	210	119
Oaks	149	57	61	19
Ash	94	183	120	61
Pecan-hickory	85	33	41	13
Sycamore-sweetgum	3	15	23	6
Cottonwood-willow	1	10	8	10
Miscellaneous	131	145	51	45
Totals	1432	1355	960	619

(figures indicate mean number per acre)

Source: Hosner and Minckler, 1960.

Exceptions to this relationship were found for cottonwood, willow, sycamore, and sweetgum. The authors observed however, that this trend was reversed by ages three to five, especially for boxelder, hackberry, cottonwood, willow and silver maple (Table 4).

TABLE 4. Seedlings three to five years old by species and diameter of canopy openings, where h equals height of stand.

Species or Species Group	Diameter of Openings in Canopy 0	<½h	½h - 1h	>1h
Elm	134	224	213	240
Boxelder-hackberry	120	232	313	471
Silver maple	39	213	393	619
Oaks	153	146	103	189
Ash	89	273	253	163
Pecan-hickory	44	36	40	68
Sycamore-sweetgum	10	45	25	32
Cottonwood-willow	8	20	68	157
Miscellaneous	172	199	169	308
Totals	769	1388	1577	2247

(figures indicate mean number per acre)

Source: Hosner and Minckler, 1960.

They concluded that a relatively heavy canopy benefits germination and early establishment of many bottomland species, with the exception of those that

are highly intolerant, but if unreleased, heavy mortality will occur by ages three to five.

Regenerating the bottomland type

Due to the sensitivity of many of the more important bottomland species to heavy shading, their regeneration is often misunderstood. Harvesting systems which create large openings, for example, do not always lead to the establishment of the more desirable intolerant species. Stands that have been opened gradually by overthinning will be composed of similar reproduction regardless of the harvesting system used, be it selection, clearcutting, or others. The composition of the understory really depends on: (1) the sprouting ability of the species harvested, (2) the nature of the seedbed during the years preceding logging, and (3) the amount and quality of the advanced reproduction. The requirements for the natural regeneration of some species are shown in Table 5.

A closed canopy is desirable for many intolerant, light seeded species, as the seedbed will be maintained relatively free of herbaceous vegetation (Hosner and Minckler 1960, McKnight and Johnson 1966). However, if the canopy is opened gradually by the removal of individual trees, enough light will penetrate through to the forest floor to support herbaceous vegetation development rendering the seedbed poor for many hardwood species. If, however, advanced reproduction is allowed to establish on the seedbeds under a heavy canopy followed by the creation of large holes in that canopy by the harvesting of blocks of trees, the more desirable intolerant species will be favored. The importance of this relationship was demonstrated by Hosner and Minckler (1960) when they found excellent germination and early establishment of many desirable bottomland species under full canopies, but their disappearance if not released within two years following germination. Obviously, this approach will not work for the highly intolerant cottonwood or willow. For both species, open conditions with bare soil at the time of seed fall are required. Research conducted in the south even indicates the need for some site treatment under certain conditions. A river site dominated by boxelder following the harvest of cottonwood was clearcut during the spring and all overstory trees, except cottonwood, were deadened by injection. Trenches were then plowed to a depth of eight inches and a width of seven feet to create a bare, moist seedbed. With this site preparation, establishment of cottonwood was found to be excellent (McKnight, 1965) and a low-value boxelder stand was converted to a high-value species.

Good new stands of mixed bottomland species can also be created by clearcutting but to do so generally requires the presence of desirable species in the form of advanced reproduction. If not present, the composition of the new stand is left to chance and may consist of the most prolific sprouting species, not necessarily the most desirable. However, Johnson (1967 - unpublished data) found clearcutting effective in regenerating bottomland types in southern Michigan. Reproduction of all tree species of seedling or seedling-sprout origin averaged 2805 per acre across 27 stands studied and ranged from 24 to 8738 reproduction stems per acre. Moreover, 78 percent of all stands contained 1000 or more trees per acre. Stump sprouting had little impact on regeneration numbers even though red-silver maple averaged 12 per acre, American elm 6, and green ash 3. In his study, green ash followed by elm was found to make the greatest gain in numbers from pre-cut to post-cut conditions. Due to the decline in both of these species with time, however, and an increase in the

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TABLE 5. Requirements for natural regeneration of some important bottomland species.

Species	Advanced reproduction	Seed supply	Germination condition	Reaction to competition	Opening size for good growth	Treatments sometimes needed
Sweetgum	Seldom present; must usually depend on new seedlings	Abundant most years within 400-500 feet of seed trees. May also be carried by flood waters.	Moist, bare soil; thin or freshly disturbed litter; and moist	Moderately intolerant to overtopping competition. Will live 6-8 years under canopy but grow slowly.	Height of overstory trees or greater.	Ground scarification just before seed fall & release of seedlings.
Cottonwood	Seldom present; must depend on new seedlings	Abundant every year; widespread on alluvial sites carried by water.	Mud or shallow water which recedes to mud.	Very intolerant to overtopping. Crown must be in nearly full light. Will not live under canopy.	Twice height of overstory trees or greater.	Eliminate competition and provide bare soil at time of seed fall.
Sycamore	Seldom present; usually depend on new seedlings.	Abundant most years within 400-500 feet of seed trees. May also be carried by flood waters.	Moist, bare soil; thin or freshly distrubed litter and moist soil.	Intolerant to overtopping competition. Will live only 2 or 3 years under canopy.	Height of overstory trees or greater.	Release from dense competition.
Silver maple	Seldom present; usually depend on new seedlings.	Abundant nearly every year within 300-400 feet of seed trees.	Moist, bare soil; thin or freshly disturbed litter and moist soil.	Moderately intolerant to overtopping; will live 3-4 years under canopy.	Height of overstory trees or greater.	Release from dense competition.

TABLE 5. Requirements for natural regeneration of some important bottomland species, continued.

Black walnut	Seldom present; must depend on new reproduction.	Abundant most years if seed trees within 75 feet. Sometimes longer distances by squirrels.	Litter not seriously inhibiting. Best to have seed covered by mineral soil.	Intolerant to overtopping competition.	Height of overstory trees or greater.	Distribute and cover seed; release seedlings from competition.
Green Ash	Often present in stands with green ash in overstory. Will form new stand after cutting if present.	Abundant most years if seed trees within 300-400 feet.	Moist bare soil; thin or freshly disturbed litter and moist soil.	Fairly tolerant to competition. Will live 8-10 years under canopy, but make little growth until overstory cut.	Three-fourths height of overstory trees or greater.	Release from dense overtopping competition.
Pin oak	Often present. Occurs as seedling sprounts which die and resprout periodically.	Abundant every 2-4 years if seed trees within 100 ft. longer distances by squirrels. Pin oak most prolific; two good seed years in three.	Litter not seriously inhibiting. Acorns will germinate under litter in spring.	Moderately tolerant to competition. Will live many years under canopy as seedling sprouts, but will not grow. Pin oak is most intolerant.	Height of overstory trees or greater. One and one-half height for pin oak.	Release if advanced reproduction overtopped by undesirable species.
Swamp white oak	Often present. Occurs as seedling sprouts which die and resprout.	Abundant every 2-4 years if seed trees within 100 feet.	Litter not seriously inhibiting.	Moderately tolerant; will live many years under canopy.	Three-fourths height of overstory trees or greater.	Release if advanced reproduction overtopped by undesirable species.

Source: Illinois Technical Forestry Assoc., Inc., 1972.

importance of maples, he concluded that red-silver maples would ultimately prevail on the sites.

Minckler (1958) likewise found a favorable response from clearcutting in southern Illinois. Reproduction three years after clearcutting was composed chiefly of desirable species. Seventy-seven percent of the seedlings and 84 percent of the saplings were ash and silver maple. However, the plots contained 2570 seedlings and 180 saplings of desirable species (mostly ash and maple) at the time of cutting.

If clearcutting is used, it is important that competing vegetation be eliminated to permit the desirable regeneration to develop. Too often, cull and weed trees occupying the understory of a mature hardwood stand are overlooked. To enhance the development of desirable regeneration, these trees must be either cut or deadened.

CONCLUSIONS

In general, most bottomland hardwood sites in the upper Mississippi Valley will contain an adequate number of seedlings of desirable species for natural regeneration. With the exception of cottonwood and willow, other major species are able to germinate and become established initially under a wide range of soil and site conditions, although their numbers will vary significantly from area to area. Complete release within two years following germination, however, is necessary to obtain adequate growth and to favor the more desirable intolerant species. Open conditions with bare soil at the time of seed fall are required for the establishment of cottonwood and willow.

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QUESTIONS AND DISCUSSION

Question: Has there been any work done using herbicides in combination with scarification as a means to establish cottonwoods or silver maple?

Answer: (Gene Garrett) There has been a great deal of work on cottonwood, especially further south. To my knowledge there has been nothing, however, on silver maple. Obviously, cottonwood does require a bare soil. If you want a good establishment, you are going to have to make sure that the soil is bare. In many instances, they have gone in and used herbicides. Normally, in the south, of course now they just use mechanical scarification, and that is more than adequate.

Question: What effects is flood control on the Mississippi River having on the distribution of bottomland forests?

Answer: (Gene Garrett) That is a good one. I agree. I don't really know. I can't respond to that because I really don't know what effect it is having. I would think, obviously, that with any regulation of flooding, you are going to increase the speciation of these individual stands and you are also going to expand the area covered by these stands. But, I did not find anything specific in the literature that would indicate that.

Question: Question on the timing on the creation of openings in hardwoods--a little unclear--were cuts made after the seedlings were established?

Answer: (Gene Garrett) Obviously, where the bottomland hardwood species are concerned, most of them being intolerant, as a matter of fact, the literature suggests that in order to get adequate growth of the material after it is established, you have to have 1/3 to 1/2 full light intensity. Now with the sun to Zenith, we are talking about 10,000 foot candles; or roughly 3,000 to 5,000 foot candles light intensity to accommodate the basic growth needs of most of these species. As you will recall from the one slide that I showed, many of these species establish themselves extremely well under very little light intensity. Seedlings that are one to two years of age will be extremely prominent. Unless you open the canopy up, those numbers start to decline. So, what I am suggesting is, that if indeed you have the amount of regeneration that you need on the site, that you get in and start opening up the site. On the otherhand, if you are dealing with species that are extremely intolerant, and you have to proivde a little additional light for them, I am suggesting that you go in on the site and a slight thinning from below somewhat similar to what Paul Johnson suggested in the upland type. Get them established, and then go back in and open up the stand. Your irregular shelterwood, for example, conceivably could have as many as three to four cuts involved in order to maximize the establishment of the regeneration. If the material is there, you go on in and open it up. Give it light, let it take off. It it isn't there, then you go in and conduct a thinning from below. You allow a little more light to penetrate, get the material on the site and then you go back in and start opening up the canopy.

PRODUCTION AND HANDLING OF PLANTING STOCK

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INTRODUCTION

First of all I'd like to thank the University of Minnesota for the title of Dr.--as indicated on correspondence prior to this gathering. The truth is I don't have any such degree. But my new title of Research Scientist, as indicated on this program announcement--I'll accept. I believe we're all research scientists in that we are all looking for better ways of accomplishing and improving upon the science of silviculture and reforestation.

When first asked to come here and speak on Production and Handling of Planting Stock--I was flattered, and having produced planting stock for several years, I felt qualified to take on the assignment. But last month as I attempted to rough out an outline for the topic, the idea of speaking at a Hardwood Regeneration Conference began to concern me more and more. Like most nurserymen I feel proficient in growing conifers, but when it comes to hardwoods my experience and confidence is limited to far fewer species.

The production of hardwood planting stock for reforestation has been on a smaller scale and more specialized than conifers. Many hardwood plantings in the Lake States have resulted in failure. This has led to the almost exclusive use of coniferous species in reforestation on all types of planting sites because satisfactory survival and growth of conifers was much more certain. However, the demand for hardwood seedlings has increased during the past several years and numbers of hardwoods shipped from state, federal and industrial nurseries has increased. Probably the reasons for this increase are (1) the demand for hardwood timber and (2) recent foresters ability to establish successful hardwood plantations. Successful plantations have been established in open field and clearcut forest sites, and nursery grown seedlings have been planted after regeneration cuttings to improve the composition of the new stand. I know in the Lake States the stands where elm dominated are high priority for hardwood reforestation. Regenerating our beautiful pure stands of paper birch has challenged reforestation foresters. Red oak, yellow birch and white ash are being planted in numerous situations with varying degrees of success on National Forests in the Lake States.

Hardwoods as a group are more difficult to grow than conifers because the hardwoods include many species that differ in seeding habits and nursery requirements. Also, hardwood seedlings are more exacting in their soil requirements than most conifers. Thus, the best portions of a nursery, in terms of soil texture, surface and internal drainage, and soil pH are used to produce hardwood seedlings.

Techniques required to grow hardwoods are different than for confiers, but the basic principles are the same. A prerequisite for producing quality seedlings, whether conifer or hardwood, is quality seed. Quality seed in my

opinion must be collected from quality trees (or stands) from the same or a proven compatible seed zone to that which the seedling will eventually be outplanted. I'm sure most everyone here has seen enough progeny and provenance studies to convince them of this all important prerequisite for quality planting material. Dr. Wilde once told me that if a child picks the right parents he has won half the battle of life. Well, we know a child cannot pick his parents, but we as foresters can select good quality stands from within compatible seed zones for seed collection.

Nurserymen and foresters should constantly watch for potential seed sources for all species grown or that might be grown at their nursery. Potential collection areas should be marked and recorded showing species, amount of seed that may be expected, and frequency of good seed crops. Seed orchards and seed production areas are being developed at some nurseries to provide high quality seed. The U.S. Forest Service Seed Orchard serving the Lake States National Forests, located near Lakewood, Wisconsin, is already paying off. Genetically improved 3 year old white spruce seedlings produced at Toumey Nursery from our seed orchard seed will be distributed to national forests for outplanting this spring. Apparent blister rust resistant 3-0 white pine seedlings will be available starting next spring. Hardwoods by no means have been left out of our tree improvement effort. For the past several years we have been establishing clonal orchards for nearly all major hardwood species native to the Lake States.

The first step in accomplishing genetically improved planting stock is identification of superior trees in the forests. These are trees that have surpassed all neighboring trees of the same age and species and display desired qualitites (form, straightness, bole height, resistance to insects and disease, etc.). By collecting small branches, called scions, from the tops of these superior trees and grafting them to potted root stock, duplicates (clones) of the parent tree can be made many times. These grafts, capable of producing seed in just a few years, are shipped to our seed orchard, and will be used as the main source of high quality seed in the future.

Before I get to the production and handling of planting stock I believe it important to mention briefly something about collection, handling, extraction and storage of tree seed.

COLLECTION--Many species of trees produce a bumper crop of seed only once in 4 or 5 years, and a fairly good crop once every 2nd or 3rd year. It's to the advantage of the collectors to concentrate seed picking in these years when cones or fruits are plentiful. Also, seed obtained in years of good crops will generally be of a higher viability and cheaper per pound than lots collected in lean years. Foresters must be able to recognize ripeness of seed and know when and how long the seed collecting period will last for the various species.

HANDLING--Freshly collected fruits of practically all hardwood species will heat if piled or sacked and left undisturbed for any appreciable length of time. Heating will destroy seed viability. Seed of most species should be extracted by the nursery as soon as possible after collection and put into cold storage until sown or until prepared for long-term storage. Deliver

seed to the nursery as soon as possible and your worries are over.

SEED EXTRACTION--The nursery will extract the seed from the cone or fruit by varying procedures depending upon the type of fruit being processed. Hardwood seed, for the purpose of extraction, is divided into three main classes--dry fruits, fleshy or pulpy fruits and nuts.

STORAGE--Seed of many hardwood species should be sown immediately after collection and extraction. However, surplus seed from bumper seed crops should be stored to furnish adequate seed for poor seed years. Hardwood seed is more difficult to store than that of most conifers. However, storage methods have been developed for most of the hardwoods.

For specific information concerning collection, handling, extraction and storage of tree seed for the various conifer and hardwood species the following referenced handbook is as good as any. Seeds of Woody Plants in the United States, Agricultural Handbook No. 450, Forest Service, U.S. Department of Agriculture. Also there is a Hardwood Nurseryman's Guide, Agricultural Handbook No. 473, Forest Service, USDA which is an excellent reference.

PRODUCTION--The growing of trees in a nursery involves an intensive form of management, particularly when the nursery is to be in continuous production for many years. It should always be kept in mind that the trees produced by a forest tree nursery are primarily for reforestation or windbreak planting and will be harvested as a forest crop or relied upon to provide resource protection. The conditions under which the stock are to be planted out (that is, the site) should be known, and this knowledge should govern the treatment the stock receives in the nursery.

Generally, proper species selection for conifers is recognized--I don't believe we have as good a handle on hardwoods. The next speakers, Paul Johnson and Ed Hayes, will address this subject. Of equal importance to proper species selection are morphological and physiological seedling characteristics such as diameter, root mass, root:shoot ratio, height, nutrient content, etc., of the trees.

It is imparative, therefore, that the forester who has to establish and manage new forests should discuss with the nurseryman the type of stock he desires, and that the nurseryman should supply this stock to him. Research, nurserymen and users of tree seedlings should collaborate on target definition of desirable seedlings for specific planting site conditions. I believe that tailoring seedlings to the site is important, especially on droughty sites. The more often a forester from the field goes to the nursery and views his stock the better. Trees of poor quality are better destroyed and usually are destroyed rather than shipped to the field where they are not wanted. The forester in the field must remember, however, that the production of trees in the nursery is subject to infrequent catastrophies over which the nurseryman may have little or no control.

I belive that if the nurseryman is provided with high quality seed and accurate technical seedling specifications for each tree species and for the major classes of site conditions, he has an excellent chance of pro-

ducing a seedling that will survive and perform well.

There are several factors that effect the seedling quality in the nursery up to the time of lifting. Broadly, these factors are:

A. Nursery site factors: soil, fertility, moisture, climate, weather. The first factor to consider in the production of hardwood seedlings is the soil. Hardwood seedlings are more exacting in their soil requirements than most conifers. Heavy soils should be avoided. Poor drainage leads to reduced growth and health of seedlings in clay/silt soils. The soils management program in a tree nursery will directly affect the yield, size and quality of the seedlings produced. Some special soil concerns to the hardwood and conifer nurseryman are (1) maintenance of soil texture and soil structure, (2) maintenance of soil organic matter, (3) use of green manure crops, (4) maintenance of soil pH, and (5) use of commercial fertilizers.

B. Time of sowing and length of growing period, including age of seedling, and time of year seedlings are lifted clearly affect the quality of seedlings being produced. The seedling must be sowed at the right time, fertilized and irrigated at the right time to fit natural growth cycles, and seedlings must be lifted while dormant.

C. The space occupied by the seedling in the nursery bed is critical. Seed should be sown at optimum spacing. Seedling quality depends materially on the space allotted to the individual seedling. It affects root collar diameter, height growth of seedlings in all conditions, often for several years after planting, and survival in adverse conditions. At J. W. Toumey Nursery we are producing hardwoods at an average of 10 seedlings per square foot and conifers at an average of 25 seedlings per square foot.

D. Weed Control--nursery beds should be maintained in a weed free condition so as to allow maximum growth and vigor. Soil fumigation, mechanical weeding, herbicides and hand weeding are all effective tools. Herbicides and mechanical weeding are used to control the bulk of the weeds in our nurseries. Different species require quite different herbicide regimes, and "fine tuning" has to be applied to each nursery if optimum results are to be obtained.

E. Seedling Nutrition--proper nutrition is of great importance in producing quality seedlings. Nursery soil and foliage analysis results assist the nursery manager in determining fertilizer needs. Quantity and timing of applications is of prime importance.

F. Seedlings of some species can be pruned in the seedbeds. Seedlings are top pruned and root pruned to control size, stimulate fibrous root growth, and develop uniformity and increase root: shoot ratios. Seedling hardiness can be improved by root pruning along with carefully controlled fertilization and irrigation.

NURSERY PROTECTION--Seedbeds require protection from drying winds, flooding, excessive heat, excessive cold, drought, mammals and birds, insects and diseases. Effective registered fungicides and insecticides must be available to the nurseryman as they are often necessary to maintain seedling health. Insects are often detected and controlled without any great difficulty at the nursery. Fungi, on the other hand, may be less easy to detect and to deal with. Root rot fungi are particularly difficult to detect and to deal with. Root rot fungi may not be readily apparent on stock sent out for planting, but affected trees may later die or show severely reduced growth.

SEEDLING HANDLING

A. The survival and performance of hardwood seedlings is dependent upon the time of year they are lifted. Seedlings may be lifted either in the fall as soon as they are safely hardened off, or in the spring. Hardwoods are usually hardened off after the first few frosts, the occurrence of low temperatures, or after seedlings lose their leaves. Some species are ready to be lifted earlier than others. Hardwood seedlings do not remain dormant very long in the spring after the weather becomes warm so it is advisable to dig them in the fall or very early spring.

B. Survival and performance of hardwood seedlings is dependent upon the condition of nursery beds at time of lifting--we must reduce conditions in which the trees may be stressed. Seedlings should neither be lifted when the soil is frozen nor when their roots would be exposed to freezing temperatures.

C. Survival and performance of seedlings is dependent upon methods of lifting, sorting, packing, grading, root pruning, storing and transporting. Everything we do to the seedlings including and following the lifting process will affect survival and performance. Recommended storage and handling practices must be followed until the seedling is properly planted.

   Hardwood seedlings can be stored safely for long or short periods. It is imperative, however, that seedlings be hardened off before they are lifted for storage. Seedlings should be planted before bud-break. Cold storage in refrigerated rooms is a preferred storage method. The temperature should be kept just above freezing (33^{o}-38^{o}F.) and relative humidity of 70-85%. Research findings recommend that fall-lifted nursery stock of white ash, sugar maple, red oak, basswood, paper birch, and silver maple be cold stored at a temperature of 33^{o}F. and black walnut at 40^{o}F with a relative humidity of 70-85%. Roots should be surrounded by moist peat and the total seedling enclosed with a Kraft bag with a polyethylene liner. Research has indicated that root regeneration capacity of cold-stored seedlings is significantly correlated to shoot xylem water potential at time of removal from cold storage. Shoot xylem water potential may offer a useful and rapid measure of seedling physiological quality. The U. S. Forest Service has recently purchased Plant Moisture Stress Meters (Pressure Bombs) for all

Lake States National Forests. I suggest that all field foresters involved in reforestation (especially those that purchase, transport, handle, and plant seedlings) consider using one of these devices in evaluating planting stock quality. It may very well help you discover what went wrong or right with your planting program.

Any treatment where roots are allowed to dry out, or where trees are heated is detrimental to stock quality. The form of packaging is important. Plastic bags are unsatisfactory because they allow trees (especially roots) to be damaged or broken during transport, and also because, should they be left in the sun, the trees will cook, severely reducing viability. Packages should be firm. If trees are packed too tightly they tend to heat, if too loosely the tend to dry out; in both cases survival and performance are reduced.

Seedlings should be in transit as short a time as possible. Refrigerated trailers should be used, especially for long hauls. If refrigerated trucks cannot be used, then an enclosed truck may be used for short hauls. Open truck hauling should not be permitted unless heavy light colored canvas tarps are used. Trucks without refrigeration should not be parked in the sun. Short term storage at or near the planting site should maintain as close to refrigerator temperatures as possible coupled with high humidity. Storage rooms should be disinfected prior to use and space should be allowed between packages of trees for good air circulation. Fans could be rigged to further improve air circulation.

D. Survival and performance of seedlings is dependent upon proper handling and planting on the forest site. The same stock handling procedures mentioned previously apply to the stock once it reaches the field. I don't believe there is any need to elaborate here on the importance of proper planting and its effect upon the seedling establishment. In operations where the whole sequence from lifting to planting is not rigidly controlled, the loss of tree vitality is considerable. Poor practice probably has a more detrimental effect on survival and growth than any other part of the establishment system.

E. Weather conditions before, during and after planting can have a profound effect on plantation survival. For example, a poor quality seedling (one that was not properly hardened off, poorly balanced or not properly handled) may survive and grow well on a sheltered site or an unfavorable first growing season. A well hardened seedling or well balanced seedling of the same age, species and size may survive and perform well in both the above situations.

F. Other factors which affect field performance and survival are the conditions of the site, adequacy of site preparation, site factors, methods of releasing seedlings from weed competition and animal damage. These factors will be covered in detail by other speakers on the program.

I was asked to include some discussion on container-grown hardwoods for reforestation.

Only a few percent of container-grown seedlings produced annually are hardwoods. I do believe, however, that their popularity will continue to increase.

Planting container-grown hardwoods is most successful when the stock is dormant but ready to grow new roots. The planting site must have adequate moisture and must remain that way for some time. Suitable transportation and storage at the receiving end must be available, and the stock must be properly cared for. The tree planter must have the proper equipment and he must be motivated and know how to do a good planting job. After it is outplanted, the seedling must quickly extend its roots into surrounding soil and grow in height to dominate competing vegetation.

The keys to good field performance are proper physiological condition, the right balance between shoot and root and adequate size. Buyers of nursery stock are often mislead by large tops, but often there is not sufficient root area to support a large top after outplanting.

Fortunately there is more leeway with dormant hardwoods than with conifers because of the absence of leaves (less transpiration water loss).

For most hardwoods it is recommended that a minimum container size of 10 cu" and preferably 25 cu" be used.

Container stock should be used on harsh sites where increased survival is needed. This could include almost any place on the Plains. It includes southfacing slopes and sandy upland soils throughout the country. Do not plant when weather conditions are completely wrong. Do not use too small a container. Small seedlings fall victim to hazards such as sand blasting, sunscald, or overtopping, to which a larger seedling would not be susceptible.

When the container seedlings arrive, stick your finger into the pot and see if the soil is moist. If it is dry, water them immediately. For storage container seedlings need protection from wind and direct sun, they need to be watered when dry. They can be stored against the north side of a building or along the north edge of a shelterbelt. If there is no other place to store them they can be put in a cold storage facility designed for bareroot stock. However, nothing must be piled on top of the seedlings directly. For additional information on container grown hardwoods a starting point would be to write for two publications by Dr. Richard Tinus entitled, "How to Use Container Stock" and "Use of Container Grown Hardwoods for Reforestation". They are referenced in this paper which can be found in the proceedings of this conference.

In conclusion I'd like to make the following comments. Seedling quality is ultimately measured by field survival and early growth. All experiments to investigate seedling quality and reforestation need to be very carefully controlled and repeated. The number of variables affecting the seedlings is very wide throughout the whole process of growing, handling and planting,

including the effects of both the nursery and the forest site, and site preparation methods, and genetic variation.

I recently read a parable in Daily Guideposts, 1977 about a farmer who went to his fields each night and returned complaining to his wife that his seedlings were growing too slowly. Finally, he became so anxious that he walked between the rows and gave each plant a slight tug, hoping it would help them to grow, but the next morning to his chagrin all the seedlings were withered and dying. One person concluded the fable by adding, "Few there are among us who don't tug on seedlings".

"Teach me, Lord, how to wait - and joyously anticipate."

All too often in our haste to correct or improve upon a reforestation practice we rely on measurements and information collected over a very short period of time. Entire programs are altered, at great expense, based upon studies and reports conducted over one to two growing seasons. I believe that at times management takes on a faddish look. It is particularly important in reforestation that experimenters proceed carefully--with their eyes wide open. Because of the long term effects of reforestation practices, it is also very important that precise records be kept.

Dr. S. A. Wilde, world authority on nursery soils and especially forest soils in the Lake States once read me a poem he had written titled, "On Limitations"--I would like to read you the first and last verses of that poem.

"No matter what you may wish to innovate,
Of this you must be deadily sure;
No mortal ever could create
Strawberry jam from horse manure!"

"As destined, all that exists
On earth has limited duration
Except stupidity, which persists
Without the slightest limitation!"

Haphazard or substandard nursery stock growing, handling and planting procedures have cost the taxpayers many millions of dollars in past years. We can greatly reduce these losses by better organization and team work. Quality reforestation will always be dependent on constant attention to quality control.

It's been a pleasure speaking to you. I would be happy to try and answer any questions you may have.

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QUESTIONS AND DISCUSSION

Question: At the time of planting, is it alright to have seedlings in a bucket of water or should they be in a litter slurry in the bucket?

Answer: (Paul Forward) I feel that it is important that the roots of the seedlings be moistened prior to planting. Obviously, if they are coming out of a bag of trees with heavy wet soil on the roots, I wouldn't recommend or feel it necessary to submerge those seedlings in water. If you had some moss or other packing material, just to keep those fine root hairs from being exposed to the air, that would suffice.

Question: What is the best way to store acorns?

Answer: (Paul Forward) I have attempted to store acorns in a number of techniques. A person could store oak if they had the facility and refrigeration unit and could maintain the humidities--it would be a good investment. But, for practical application, it is extremely difficult. I have burried them in soil down to four feet, to get about 40 degrees. They recommend the upper 30's and with moisture content, 15 to 20 percent. I've burried them overwinter, and put them in sawdust, put them in drums, put them in a cold storage unit, and froze them at 20° F. I've tried all types of techniques with no real success. Your working with oak is dependent upon a good acorn crop that fall. We are producing both one-year old red oak and two-year old red oak. We don't really know what size seedling will perform and survive the best. But, by working with both age classes, it does provide us with flexibility if we have a good bumper crop one year, we can take care of two years of planting needs.

Question: Why is ventilation of the seedling storage areas necessary if the seedlings are stored in bags?

Answer: (Paul Forward) Ventilation is important in storage of tree seedlings to remove gas exchange and to prevent mold. Stagnant air is very favorable for fungi. You have high humidity, you have got temperature (anything above 32 you are going to have mold development). If you got air circulation, you are going to keep the pathogens from having that opportunity to sit in that stagnated environment and penetrate your root systems.

MATCHING HARDWOOD SPECIES TO SITE

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Matching species to site is not easy. However, by the end of this paper, we hope that we will be able to make this task less difficult. As forest managers, it is becoming increasingly important to match species to site for the greatest dollar return from timber management. It is also an important consideration in wildlife, recreation, or improvements to the environment. Every dollar invested must yield a return; therefore, forest managers cannot afford to invest large amounts of dollars on poor sites that will not respond to such high levels of management.

Matching the right species to the right site is the first of many management decisions that will be necessary to successfully establish and produce quality hardwood products. In fact, the most important factor in the establishment of a successful hardwood plantation is the selection of a suitable planting site. Most hardwood species are very demanding and selective in their site requirements. Therefore, the closer the match between the optimum requirements of the species and the actual conditions of the planting site, the greater the probability that the plantation will be a success (1).

In a recent paper, Carmean (3) suggested four methods for establishing site quality:

1. Using tree height and age measurements in conjunction with site index curves.
2. Using site index comparison graphs that convert observed site index to site index for alternative tree species.
3. Using soil-site methods of site quality evaluation when trees for site measurements are lacking.
4. Using soil surveys.

For the purpose of this paper, we will be taking a detailed look at the soil-site method by reviewing the physical soil properties that characterize a given site's potential for providing hardwoods regardless of whether trees are present or absent. The forester's objective is to match as closely as possible the specific requirements of hardwood species to specific soil-site features that can be determined in the field.

IMPORTANT SITE SELECTION FEATURES IN TRI-STATE AREA

Topography

1. Aspect, slope position, slope steepness, slope shape.

Climate

1. Annual rainfall, growing season rainfall
2. Wind
3. Temperature

Soil

1. Surface soil depth, depth to mottling, depth to impermeable layer, effective soil depth
2. Stoney content
3. Texture
4. Structure and drainage
5. Subsoil color and mottling
6. Parent material

The topographic features play a significant role in river, hilly, and valley type terrain characteristic of the tri-state area of southeast Minnesota, northeast Iowa, and southwest Wisconsin. This region is characterized with deep river valleys, steep side slopes, and rolling uplands. These features can have a direct influence on productivity.

South and southwest facing slopes receive more solar radiation; thus, they are generally hotter and drier. Also, south slopes with poor soils tend to be far less productive than similar soils on north slopes. The east facing slopes are exposed to direct sunlight except during the cool part of the day; thus, these slopes are cooler than the west facing slopes. West facing slopes are exposed to prevailing winter winds; thus, they have the most severe environment during the winter.

Aspect and slope can increase or decrease the site index: (a) on south to southwest aspects, the site index decreases with increasing slopes; (b) on north to northeast aspects, the site index increases slightly with increasing slopes; (c) from southwest to northeast aspects, there is an increase in site index.

Convex surfaces are more exposed to high winds, more exposed to weathering and erosion, and are drier and less fertile than concave surfaces. Concave surfaces are more sheltered; soil accumulates in them; they tend to be moist to well drained and fertile. All these factors tend to make them productive sites.

On steep slopes, soils tend to be shallow with limited amounts of moisture and nutrients available for vigorous tree growth. The site productivity on steep slopes is lower than that of the gentle or nearly level topography. Climatic features have a significant impact on the seedling environment; therefore, each site must be investigated thoroughly. The form, duration, and seasonal distribution of precipitation affect the availability of moisture. Slow gentle showers allow a greater percentage of water to soak into the soil (6).

Wind increases the rates of evaporation and transpiration by removing insulating layers of humid air that accumulate adjacent to the leaf surface.

Wind can damage trees during cold weather when both the water-supplying power of the soil and the flow of water through the plant are restricted. Exposed ridges, high convex surfaces, deep valleys and/or gorges are all subject to high winds (6). Thus, trees growing on these sites are prone to winter wind damage. Wind also may cause sufficient damage to foliage which, in turn, may reduce photosynthesis.

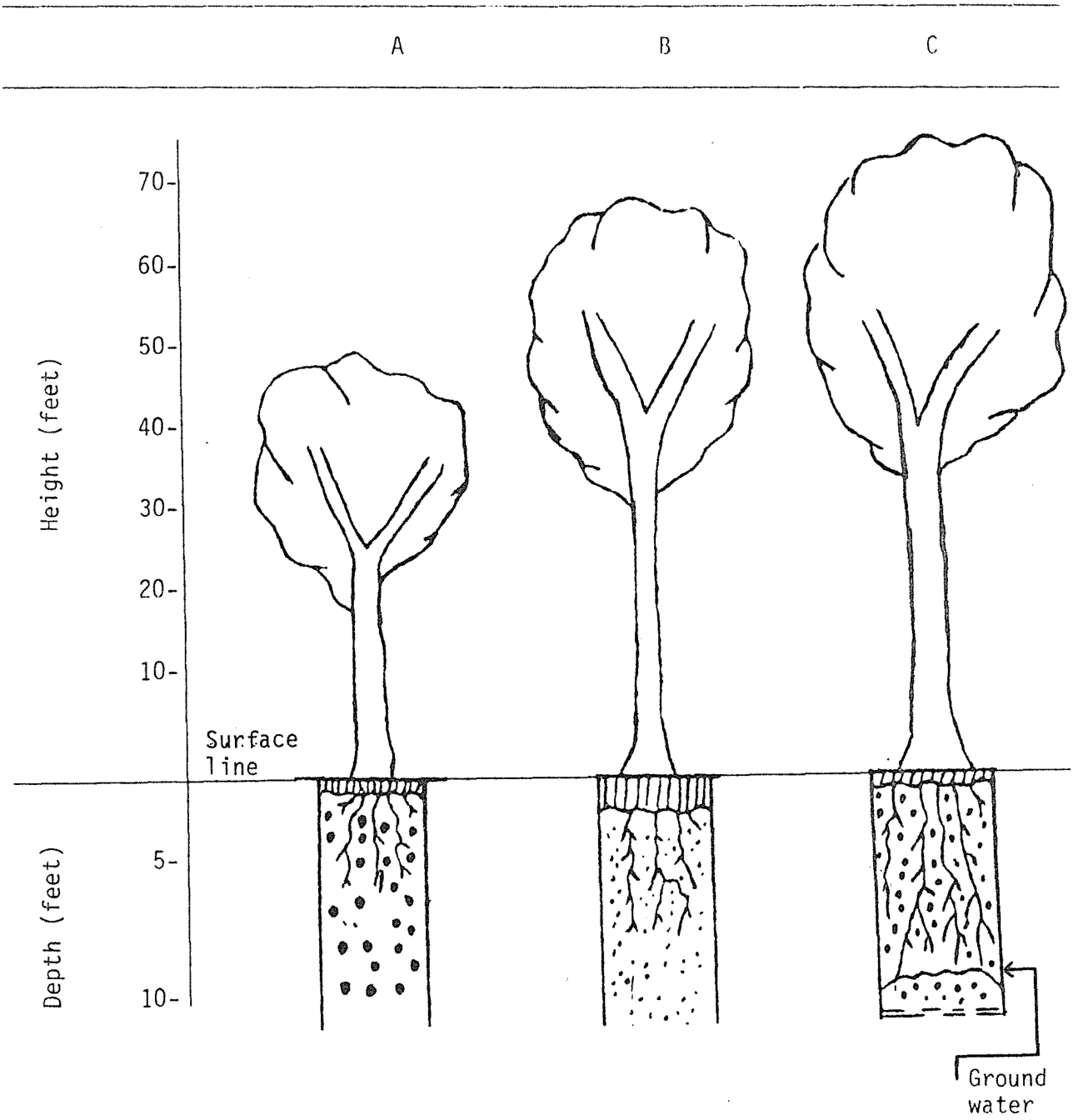
Soil texture, structure, depth, and drainage affect the seedling environment by influencing the soil temperature and the availability of moisture and nutrients. The soil environment must be friable enough to allow moisture intake; free exchange of gasses, providing proper rooting depth plus elongation; and have a supply of nutrients available for vigorous plant growth (Figure 1). Through random or systematic borings the effective soil depth, top-soil thickness, texture, structure, percent stoney content, moisture conditions, and clay content can be estimated. The effective depth of forest soil is that portion of the soil capable of being occupied by the roots. Impermeable bedrock or other physical obstructions to root penetration (hardpans, coarse fragments, or rocks) reduce the effective depth. Shallow soils (less than one foot deep) frequently have a limited supply of water and nutrients and provide poor anchorage for tree roots (6). Generally for hardwood species, the acceptable depth begins at a minimum of 36 inches. Generally for hardwoods to grow vigorously, soils should be deeper than 36 inches. Soil texture influences the water holding capacity, available water, and root elongation. Generally, most hardwood species are well adapted to deep, fertile, moist to well drained loams, and medium textured soils.

Poorly drained, heavy textured soils will greatly restrict or limit the species to plant. Mottling, the color associated with poorly drained soils, is a layer of spots or blotches of different colors or shades of colors and indicates a layer of water saturation and, hence, poor drainge. In well drained soils, the color is influenced by the oxidation of iron and manganese and in such soils the colors are red, yellow, and reddish-brown, reflecting the well drained, or oxidized, condition. In poorly drained soils where oxygen is deficient, subdued shades such as grays and blues predominate. In a poorly drained soil there will be alternate streaks of oxidized and non-oxidized or reduced materials. This mottled condition indicates a zone of alternately good and poor aeration, a condition not conducive to proper plant growth.

Restrictive internal drainage causes poor aeration and leads to poor plant growth. Good internal drainage provides the development of extensive root systems, allowing for a more complete utilization of moisture and nutrients. Hardwood species require well drained soils; it becomes very important to make the determination in the field. Table 1 shows a method for estimating internal drainage in the field by use of soil colors.

The effects of soil surface color on seedlings established depend on the heat tolerance of the species being established and other site characteristics. On bare soil, a dark surface may cause critical moisture stress sooner because increased evaporation rates deplete soil moisture quickly. Shade reduces soil and air temperature extremes (5).

FIGURE 1. SOIL INTERNAL ENVIRONMENTAL EFFECTS UPON TREE GROWTH



A. Poor growth on gravelly sand subsoil with an inadequate supply of water and nutrients.

B. Accelerating growth on medium textured soil where initial growth was retarded by weed competition.

C. Rapid growth upon roots contact with soil water.

Table 1. Estimation of Internal Drainage Based on Soil Color (2)

DRAINAGE CLASS	COLOR (MOTTLING)	POSSIBLE TOPOGRAPHY
Very slow	Drab and blue below 8 in.	Swampy, high water table.
Slow	Dull yellowish-brown below 14 in.	Low areas
Fair	Yellow 14-24 in.	Level upland
Moderate	Brownish-yellow below 35 in.	Rolling upland
Good--fast	Yellowish-brown	Terraces
Good--very fast	Red-brown	Morraines or loose sand

Another important fact that cannot be over stressed in successful hardwood plantation establishment is the control of broadleaf weeds and grasses. Both may deplete moisture so quickly that seedlings must survive for several months each year with little available moisture (6). Weed control is a must to insure successful hardwood establishment.

Although each site differs, collectively they possess within a range similar chemical or physical characteristics that will allow us to group sites for management purposes. Generally, sites may be categorized as (1) good, (2) medium (moderate), (3) poor (marginal), and (4) very poor (Table 2). Good sites quickly produce large trees, thus rotations are shorter and compound interest on forestry investments is minimized. The most valued tree species require better sites. Good sites may also be more responsive to intensive silviculture practices (4). In the tri-state area, the medium (moderate) sites are prevalent. Species choice and spacing should be considered when planning management strategies for these sites. The poor (marginal) sites have severe limitations that limit the selection of species to plant. For the tri-state area, the more important hardwood species are listed in Table 3.

Table 3. Important Species of the Tri-state Area

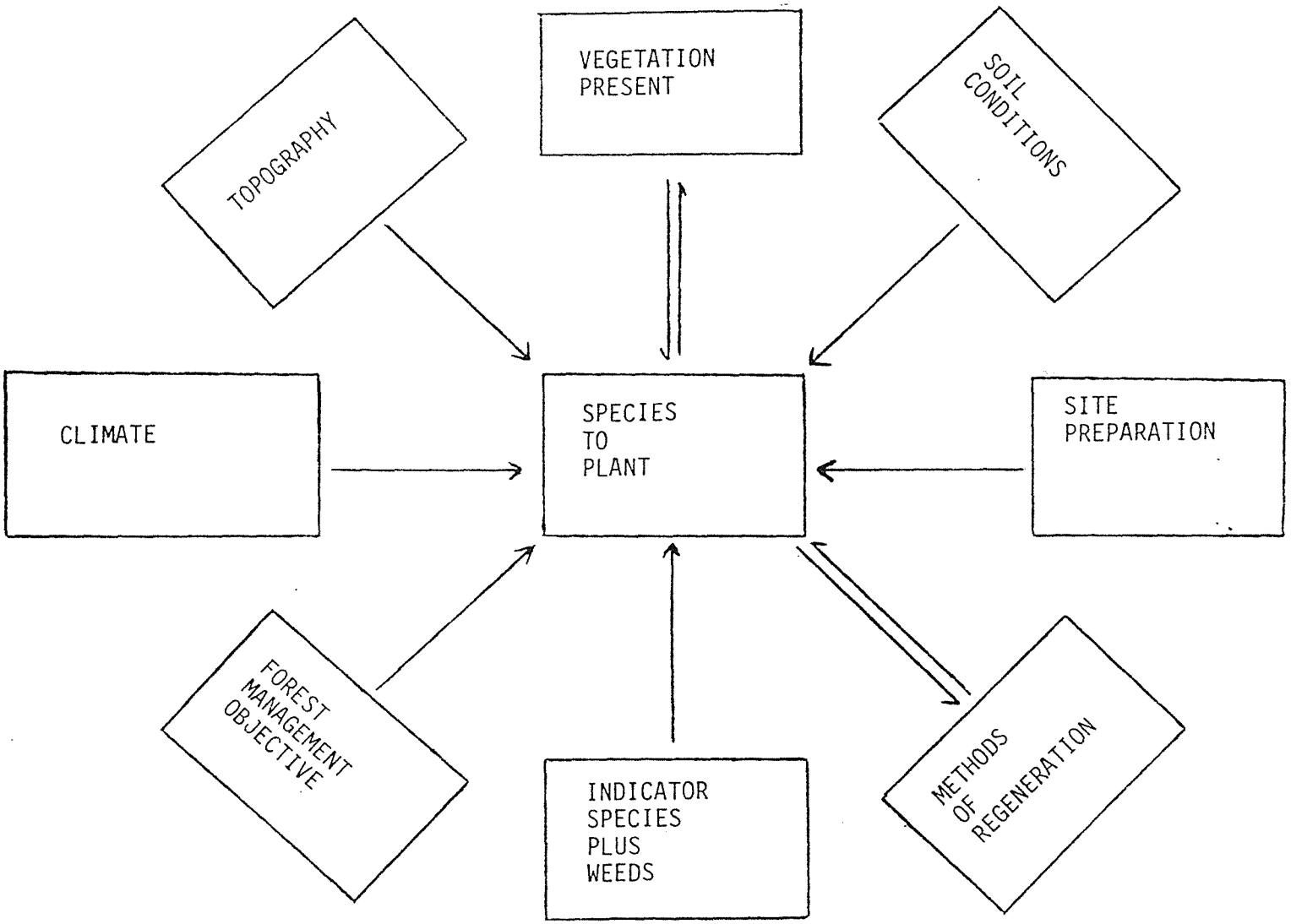
SPECIES (Prioritized Upon Highest Valued Species)
Black walnut
Red oak
White oak
White ash
Sugar maple
Basswood

TABLE 2. HARDWOOD SPECIES BY SITE CAPABILITY

Site Potential	Site Index	Species	Soil	Topography
Good	70+	Black Walnut Red Oak White Oak White Ash Sugar Maple Basswood	A. Deep, moderately and well drained silts, loams, and clays where soil depth is 3 feet or more to parent rock; sands where water table is within 4 to 10 feet of the surface.	A. On relatively flat topography broad ridges, lower slopes, bottom and valley coves; all North and East slopes where gradients are less than 20 percent; middle North and East slopes where gradients range from 20 to 35 percent.
Medium (moderate)	55-65	Black Walnut Red Oak White Oak Basswood Hickory Red Pine White Pine	A. Moderately deep (20 to 36 inches) silts, loams and clays, or deep sands with fine-textured bands in sub-soil 2 to 6 inches in thickness at depths less than 60 inches. B. Deep sands. C. Deep silts and loams.	A. On relatively flat land, upper and middle north and east slopes where gradients are less than 20 percent; middle north and east slopes where gradients range from 20 to 35 percent. B. On lower slopes in rolling topography. C. On upper and middle south and west slopes where gradients are less than 20 percent.
Poor	40-55	Black Oak Bur Oak Jack Pine Christmas Trees[1]/ a) red pine b) white pine c) spruce	A. All shallow soils less than 20 inches in depth and deep porous sands. B. All soils. C. All soils.	A. On flat topography. B. On narrow ridges and upper slopes in hilly topography. C. On middle south and west slopes where gradients exceed 20 percent.
Very poor	40	Bur Oak Jack Pine	A. All shallow soils less than 15 inches in depth and deep porous sands. B. All soils C. All soils	A. On level topography. B. On narrow ridges and upper slopes in hilly topography. C. On upper and steep south and west slopes where gradient exceed 20 percent.

[1]/ The species may be grown on any of the three sites if your objective is not hardwood production on better sites.

FIGURE 2. RELATIONSHIPS OF FACTORS TO SPECIES SELECTION



The preferred oaks and associated species in this region are summarized in Table 4 (7).

Table 4. Preferred Species for Management in the Tri-state Area and Index

SITE POTENTIAL	SITE INDEX CLASS	PREFERRED OAKS	PREFERRED ASSOCIATED SPECIES
Good	75+	No. Red Oak White Oak	White Ash Sugar Maple American Basswood Butternut Black Walnut
Medium	55 - 74	No. Red Oak Black Oak White Oak	White Ash Sugar Maple Black Walnut American Basswood White Pine Red Pine
Poor	40 - 54	Black Oak White Oak Bur Oak	Hickories Red Pine

SUMMARY

A detailed analysis is needed in site assessment to match the right species to the site. This assessment may require one or more visits before or following harvesting to adequately evaluate which species to plant. Sometimes it is very difficult to establish a site following harvesting due to an alteration in the microclimate of the site. Site may become too wet or dry to succesfully establish the desired species. The type of regeneration methods become another important factor to consider in choosing the right species. The type of environment desired depends on the species and regeneration methods chosen. The manager must evaluate topography, vegetation, soil conditions, regeneration methods, and site preparation together to determine the best species to plant (Figure 2).

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QUESTIONS AND DISCUSSION

Question: On a good black walnut site, how long do you feel you should control weed competition?

Answer: (Paul Johnson) Following the initial establishment of a walnut site, I feel that it should have weed control a minimum of 3-4 years. You may have to go a fifth year. We found no restrictive type features that should limit root elongation of walnut, so it was the grass that limited the growth.

Question: Why are the nutrient levels less on southwestern facing slopes, or is it due to moisture deficiency there?

Answer: (Paul Johnson) On your south facing slopes, due to the longer exposure, you have chemical reactions going on in the soil and as the moisture is being depleted, either evaporating at the surface or draining out latterally, some nutrients tend to be lost.

Question: What site index was referred to in your slides? Was it a soil site index, or a site index for a particular species?

Answer: (Paul Johnson) The 70 site index was for hardwoods--red oak, walnut, white oak, etc. Ahlman used 75, he used the northern red oak and the white oak as the indicated species.

Question: How do you feel about the use of the soil survey information in matching species to sites? Is it possible to involve site index from a soils map or soil type?

Answer: (Paul Johnson) It is possible, but some refinement is needed. You must remember that soil surveys are adapted to agricultural purposes and not forestry. In order to get the refinement or the detail that you need from a forestry standpoint, a forester should begin at the planning stage when this survey is initiated to make sure that the forestry needs are met because SCS regulations, policies, and laws are geared toward agronomic type problems. Due to the awareness of trees as a crop for private individuals and national forest systems, SCS is becoming more receptive to fine tuning their soil surveys to meet the needs of the user.

SELECTED HERBICIDE USES IN FOREST MANAGEMENT

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The proper selection and use of an herbicide in forestry is influenced by: 1) characteristics of the herbicide and 2) the treated vegetation, both pests and crop.

HERBICIDE CHARACTERISTICS

Important characteristics of the herbicide include: 1) foliage-absorbed or root-absorbed, 2) contact or translocated, 3) selective or non-selective, and 4) persistent or non-persistent.

Foliage-absorbed or Root-absorbed

Foliage-absorbed herbicides enter the plant through the leaves (post-emergence). Root-absorbed herbicides usually enter the plant through the roots and are generally most effective when applied before the weeds emerge (pre-emergence). Root-absorbed herbicides are often applied in combination with an herbicide having post-emergence activity. Some herbicides can be absorbed by both the foliage and the roots. Site of absorption can be influenced by formulation (granule or pellets versus liquids). Examples: (foliage-absorbed) 2,4-D, dalapon, dicamba, glyphosate, hexazinone, picloram; (root-absorbed) atrazine, oryzalin, picloram, simazine.

Contact or Translocated

Contact herbicides kill only the green portion of the plants with which they come in contact. Good coverage is necessary because they do not translocate through the plants. Most contact herbicides are non-selective. They are effective in controlling annual weeds and provide temporary suppression of perennial vegetation. Translocated herbicides move throughout the plant, whether foliar- or root-absorbed. Foliage-absorbed translocated herbicides are especially useful for controlling perennial weeds because they move into the roots. Examples: (contact) cacodylic acid, diquat, paraquat; (translocated) amitrole, atrazine, dalapon, 2,4-D, dicamba, dichlorprop, glyphosate, hexazionone, picloram, simazine.

Selective or Non-selective

Selective herbicides control only certain types of plants. When applied to mixed vegetation, some plant types/species will be noticeably unaffected. Non-selective herbicides will generally control most weed species. Selectivity may reflect physiological differences, (broadleaf weed control by 2,4-D, dicamba, and picloram, without injuring grasses), timing (glyphosate resistance by dormant conifers), application rate (control of annual weeds by simazine in black walnut plantations) or method of application (shields or directed sprays or wiping applications to prevent herbicide contact with desired species). Examples: (selective) 2,4-D, dicamba, dichlorprop, glyphosate,

hexazinone, picloram; (non-selective) amitrole, cacodylic acid, diquat, glyphosate, paraquat.

Persistent or Non-persistent

Persistent herbicides remain active in the environment for an extended period of time. Non-persistent herbicides are relatively short-lived in the environment. The degree of persistence is greatly influenced by temperature, moisture, soil type and rate of application. Persistence is important for residual weed control in new plantations or Christmas trees. Persistence within the plant is important for control of woody species or other perennial weeds. Non-persistence may be desired when applying herbicides for weed control before planting (depending on herbicide used, rate of application and species to be planted). Examples: (persistent) atrazine, hexazinone, picloram, simazine; (non-persistent) amitrole, 2,4-D, dalapon, glyphosate, paraquat.

PLANT FACTORS AFFECTING CHEMICAL WEED CONTROL

Plant Types

Most plants are either: 1) grasses or 2) broadleaves. Broadleaf plants include herbaceous forbs and many woody plants. The sedges, such as the nutsedges, are neither grasses nor broadleaves. However, they have similar characteristics to grasses and are often listed under grasses on herbicide labels.

Grasses. Grass seedlings have only one leaf as they emerge from the seed. Their leaves are generally narrow and upright with parallel veins. Most grasses have fibrous root systems. Consequently, grasses are very competitive for soil moisture. The growing point on seedling grasses is sheathed and located below the soil surface. The growing point gradually moves above the soil as the plant grows and matures. Examples: foxtail, quackgrass.

Broadleaves (Forbs). Herbaceous (plants that do not develop persistent woody tissue above ground) broadleaf seedlings have two leaves as they emerge from the seed. Their leaves are generally broad with netlike veins. Broadleaves usually have a taproot and a relatively coarse root system. All actively growing broadleaf plants have exposed growing points at the end of each stem and in each leaf axil. Examples: dandelion, mullein, pigweed, plantain, ragweed.

Woody Plants. Wood plants are those that form wood. They include: 1) brush and shrubs, and 2) trees. Brush and shrubs are woody plants that have several stems and are less than 10 feet tall. When trees are present, brush or shrubs may be called understory. Trees are woody plants which usually have a single stem (trunk) and are over 10 feet tall. Examples: hickories, oaks, pines.

Plant's Life Cycles

A plant's life cycle is either annual, biennial, or perennial.

Annuals. Annuals complete all four stages of development in less than 12 months. There are two distinct kinds of annuals--winter annuals and summer annuals.

Winter annuals germinate in the fall, overwinter, mature, set seed, and die in the spring. For best results, control winter annuals at or soon after germination in the fall. Examples: cheat, downy brome, henbit, little barley, mayweed, wild mustard.

Summer annuals germinate in the spring, grow, set seed, and die in the fall. For best results, control summer annuals at or soon after germination in the seedling stage of growth. Examples: common ragweed, crabgrass, foxtail, giant ragweed, marijuana, partridge pea, pigweed.

Some weeds are specifically winter or summer annuals. Other species can germinate and grow in either the fall or spring.

Biennials. Biennials complete their life cycle in two years. Biennial plants complete the seedling and vegetative stages of growth in the first year and the seed production and maturity stages in the second year. Biennial weeds are most easily controlled in their first year of growth. Some herbicide labels identify biennials as annuals. Examples: bull thistle, common evening primrose, common burdock, common mullein, teasel, wild carrot, wild parsnip.

Perennials. Perennials may complete all four stages in the first year and then repeat the vegetative, seed production, and maturity stages for several following years, or the seed production and maturity stages may be delayed for several years. Some perennial plants die back in the maturity stage each winter; others, such as trees, may lose their leaves but do not die back to the ground. They all reproduce by seed but many are able to spread and reproduce vegetatively. Perennials are difficult to control due to the persistent root system.

Simple perennials spread by seed, crown buds, and cut root segments. Most have a large, fleshy taproot. Examples: chicory, curly dock, dandelion, gray goldenrod, plantain, spiderwort, white heath aster, white oak.

Creeping perennials spread vegetatively with stolons or rhizomes as well as by seed. Examples: big bluestem, common milkweed, hemp dogbane, horsenettle, horsetail, poison ivy, Virginia creeper and yellow toadflax.

Developmental Stages

All plants have four stages of development:

1) Seedling--small, vulnerable plantlets; seed leaves still present; seed leaves lost, true leaves present.

2) Vegetative--rapid growth of stems, roots, and foliage. Uptake of water and nutrients is rapid.

3) Seed production--little or no growth; production of fruit. Uptake and movement of water and nutrients slow and directed mainly to reproductive parts--flowers, fruits and seeds.

4) Maturity--little or no growth; movement of water and nutrients in plant is slow.

Best control of annual and perennial weeds is best obtained when the herbicide is applied at the seedling stage of growth. As an annual plant matures control becomes more difficult. Another effective period for perennial weeds is the vegetative or regrowth stage. This causes the greatest drain on the underground food reserves. Treatment during early seed production stage is also effective for perennial weeds control. When perennials reach full flower control becomes more difficult.

With these factors in mind, consider two areas of forest management in which herbicides play an important role; plantation establishment and timber stand improvement.

PLANTATION ESTABLISHMENT

Many forest plantations are established on old field sites, especially for the nonindustrial private forest landowner. Consequently, a continuous problem is the effective control of deep rooted, perennial vegetation. Their well established root system provides a source of regenerative potential. Control is difficult when only using root-absorbed herbicides because the rates necessary to control perennial vegetation are also injurious to the tree seedlings. Contact herbicides, which kill the green foliage, provide only temporary suppression of perennial weeds. The total vegetation problem can be effectively controlled with a post-emergent application of an herbicide combination which includes a foliage-applied translocated herbicide to control the perennial weeds plus a soil-active herbicide for residual weed control. The emphasis is on "post-emergent application" because translocated herbicides without detrimental soil activity are dependent upon foliage uptake and phloem transport to reach the root system.

Translocated herbicides available for plantation weed control include gylphosate (Roundup), amitrole (Amitrol-T), dalapon (Dowpon), and the phenoxy herbicides. Glyphosate and amitrole, both highly water soluble and readily translocated, are effective on a broad spectrum of herbaceous and grassy weeds. Dalapon is more effective for grass control than broadleaf weeds. The phenoxy herbicides, such as 2,4-D provides control of many weed species. There are essentially three potential treatments for controlling a broad spectrum of weedy vegetation without serious residual soil phytotoxicity: 1) glyphosate, 2) amitrole, and 3) dalapon plus a pheynoxy herbicide.

Foliage-applied translocated herbicides must be applied in some manner to avoid contact with the seedling foliage. Shielded or directed sprays have been the common practice. Shielding may consist of a section of stove pipe, cardboard, plywood or whatever will keep the herbicide solution off the seedling foliage. Application of the herbicide mixture, particularly translocated herbicides, before planting greatly reduces the potential exposure

of the tree crop. While it is more desirable to have the trees planted as early as possible to enhance seedling establishment, soil trafficability for spraying equipment may be questionable, and pre-emergent application of soil active herbicides has limited effect on perennial vegetation.

Since the foliage-applied translocated herbicides have little soil activity, especially gylphosate, they can be easily applied with a hand sprayer. Glyphosate is particularly convenient to apply in this manner. A 1% solution can be applied to wet the foliage. Dalapon, amitrole and 2,4-D do have some soil activity although their presence in the soil is very short-lived. They should not be applied without knowing the pounds of herbicide actually applied per acre.

A new type of inexpensive applicator is the rope wick or pipe wick. Sections of nylon rope, with ends emersed in the herbicide solution, act as wicks to wipe the herbicide on the weeds. This technology has developed around a slightly diluted solution of the herbicide Roundup; generally one part Roundup and two parts water. Wipers may also consist of sponges, carpets or mops. They have been shown to be effective for applying plyphosate, although any of the foliage-absorbed translocated herbicides have the potential for being applied in this manner. Glyphosate is most popular because it controls annual and perennial broadleaf and grassy weeds. The wiping applicators are attractive because of the minimal investment, lack of drift, and reduction in amount of herbicide used. Wiping applicators may be hand-held or tractor-mounted. Weed control around individual seedlings can also be accomplished very effectively with a paint roller and 1% solution of glyphosate.

Wicking types of applicators are effective only for applying translocated herbicides to obtain control of the perennial vegetation. A properly calibrated hand or boom sprayer should be used to apply a soil active herbicide for residual weed control. Granule formulations are available which can be applied by hand.

Soil active or soil residual herbicides provide continuous weed control. The length of herbicide effectiveness depends upon rate of application, soil texture and organic matter, and climatic factors, particularly rain. Herbicides effective for providing residual weed control with seedling selectivity include simazine (Princep), atrazine (Aatrex), oryzalin (Surflan), napropamide (Devrinol), and oxadiazon (Ronstar). Simazine has been the herbicide most frequently used for residual weed control for several reasons, including length of residual activity, spectrum of weeds controlled, seedling tolerance and cost. Most conifers and many hardwood species are very resistant to simazaine. For species which are sensitive to the usual rate of simazine when applied alone, such as European black alder, a combination of oryzalin or napropamide and a lower rate of simazine should provide reasonable weed control while reducing potential simazine injury. Oryzalin and napropamide have been shown to be safe for numerous wood species. Either used alone would eliminate the simazine hazard for sensitive species. All of the soil residual materials must be applied pre-emergent to germinating weeds or after the weeds have been removed. They will not control weeds which are already green and growing at the time of herbicide application.

Soil active herbicides must be applied uniformly at rates specified by the label. Applying too little does not provide the degree of weed control

potentially possible and a second treatment may be necessary. However, a more serious problem is the potential for over application causing seedling injury or death. These herbicide treatments can be applied with hand sprayers if done carefully. Hand sprayers do not have agitation or pressure gauges. The soil active herbicides are not highly water soluble and form suspensions when added to water. Constant agitation or shaking is necessary to prevent the herbicide from settling to the bottom of the tank. A pressure gauge can be adapted to a hand sprayer to monitor pressure or regulators are available to provide a constant flow rate. Accurate calibration of hand sprayers is often more difficult than equipment-mounted sprayers.

The combination of a foliage-applied translocated herbicide plus a residual soil active herbicide allows the user to capitalize on the better control qualities of each. The translocated herbicide will control the vegetation that has germinated at the time of application, and the residual soil active herbicide will maintain weed control on through the growing season. Repeat treatments as needed, perhaps two or three times during the growing season, with non-selective herbicides such as glyphosate and paraquat can be used in place of a soil residual herbicide.

TIMBER STAND IMPROVEMENT

Timber stand improvement (TSI) is almost synonymous with individual tree treatment. Timber stand improvement is a general, popularized term which covers a host of silvicultural activities that improve stand quality by removing undesired species, trees of inferior quality or trees with low market value. There are a variety of methods for accomplishing individual stem treatment including: 1) girdle or frill only, 2) girdle or frill with herbicide application, and 3) herbicide injection in spaced cuts.

Trees can be controlled without the use of herbicides. The use of an axe or chainsaw to frill or girdle the trees is effective if done properly. These methods are considerably more labor intensive, and more costly, than the use of herbicides in spaced cut injections. Chainsaw girdling plus the application of an herbicide is only slightly faster than axe frilling alone because it is a two-step operation.

A hatchet and squirt bottle treatment is a very efficient way of controlling individual trees. A hatchet and a squirt bottle cost substantially less than specialized injection tools, are much safer than chainsaws, and are amenable to small acreages or for treating trees on an infrequent basis. The method used for placing the herbicide in the tree does not appear to be important. Several available herbicides are effective for use in tree injection, including dicamba (Banvel CST), MSMA (Silvisar 550), picloram, plus 2,4-D (Tordon 101R, Tordon RTU) and 2,4-D amine. It must be recognized that species response is influenced by herbicide selection and season of treatment. However, 80 to 90 percent control or greater is routinely possible with mixed hardwood species and injected herbicides applied throughout the year. The amine salt of 2,4-D is highly effective when injected during the growing season, particularly on oak and hickory species. Its effectiveness is reduced considerably when applied during the winter period. Picloram plus 2,4-D, and MSMA are very effective regardless of season. Although MSMA is effective for crown control, there is a strong tendency

for treated trees to produce basal sprouts. This may, however, be highly desirable for enhancing wildlife habitat.

The concept of spaced cuts is emphasized in tree injection. Often a complete girdle is used to provide insurance of total tree control, especially for trees greater than 12 inches DBH, but this is not necessary on smaller diameter trees. Control is possible by applying 1 to 2 milliliters of herbicide into cuts spaced 1 inch apart edge-to-edge around the tree. Injection can be accomplished at a convenient height when using water soluble herbicide formulations. Water soluble amine or metallic salt formulations are more preferred than emulsifiable concentrate or ester formulations. It is not necessary to inject the tree at or near the ground line for effective control. Large vines are expected to be effectively controlled by injected herbicides.

Herbicides can be very effective silvicultural tools in forest management when properly used. Herbicides are also useful for site preparation, conifer release, understory control, wildlife and recreation management, precommercial thinning and other situations where undesired vegetation is the problem.

QUESTIONS AND DISCUSSION

Question: You looked at relative cost of some of these alternative treatments given that some are roughly comparable in their results. Any economic analysis?

Answer: (Harvey Holt) No, I try not to get into economics. I just worry about whether it works or not. It looks like the wiping area is a way of reducing the costs of the herbicides per acre. This last thing that we are talking about--if you figure the time involved--if the guy walked 2 miles an hour you are just kinda lopping off a tree every now and then, that's why we just pick the trees that are up to 12 feet, because that's not a very big stem. The equipment is available that you could just snip those off as you walk along, and if you can cover a 6-foot wide strip with the lopping and with the mist blowing, we figure it as a broacast. But, you might really just be looking at creating a corridor and you just walk along and spray down this forest as you jog over and walk back. I think a treatment like this would be roughly $100 per acre.

Question: What do you recommend for total control in walnut plantations 2-4 years old, and the best method of application?

Answer: (Harvey Holt) Now, you'd like all these recommendations to be legal, too, I suspect. It's a serious problem. I have the most confidence in terms of knowing that I am legal--a combination of Roundup and Simazine. Two-three quarts of Roundup and about 20 gallons per acre with 4 lbs. of Simazine, 5 lbs. of Princep ADW.

Question: Can you outline a long-term control program for things like prickley ash and gooseberry?

Answer: (Harvey Holt) No.

Question: Are there serious drift problems with mist blowers?

Answer: (Harvey Holt) The potential, yes. But in the situation that we are talking about using here, you are in a totally encased understory. I don't think that there is a drift problem. We are not running this across a clearcut area. And, basically as we look at the results, you have a hard enough time having an effect 15 feet away from you with a back pack mist blower.

Question: Do you know of any research that has been conducted relating to weed and grass control that can be used in a field for planting walnuts, that is planting nuts instead of seedlings?

Answer: (Harvey Holt) I have no reason to believe that Simazine or Roundup wouldn't be equally as effective. In the Forest Service research from Carbondale: if you can get a nut in the ground and established, I mean if you can keep it there before the squirrels get there, you

are really ahead because if you take a 1-year old seedling and transplant it, at the end of its first year after transplant, you have a 2-year old seedling. If you put a nut there and let it grow for 2 years, its bigger than the seedling. The problem has been the squirrel predation. Otherwise, we would prefer to plant seeds.

Question: What kind of chemical do you recommend with a squirt bottle and ax to control undersirable hardwoods, percent mixture, and best time to apply?

Answer: (Harvey Holt) Okay, with tree injection you've got several materials that are labeled. Tordon 101R has been around for some time. 2,4-D Amine is very effective, especially if you are treating oaks and hickories during the growing season and that's a very effective treatment and its relatively cheap--2,4-D Amine's only, I suspect, $9-10 a gallon. It's a commodity product. Tordon 101R, or Tordon RT (they are the same products) is very effective on a broader spectrum of species than 2,4-D, and it's a little more effective in the winter season, although its effectiveness does drop off. There is another product now, Banvel CST which contains a pound of Dicamba. We've injected Dicamba, a solution that contains 2 lbs. of Diacamba per gallon, and have gotten really good results with it. The 1 lb., I don't know, I would assume that it would be reasonable. There is a product Garlan 3A which is labeled for tree injection and we can dilute it at least 1 to 1 and have really good results with it. The new lable of Roundup covers tree injection, but its labeled for full strength usage and a little wider spacing. We have not used it in that context, we have diluted it with water: 1 part Roundup, 4 parts water, so that it's in a cost comparison range with Tordon 101R, and again its a reasonably effective product.

Question: Please comment on the practicality of applying Simazine to a hayfield or sod situation as a site prep prior to planting the same spring.

Answer: (Harvey Holt) I think by applying a material like Princep to a perrennial grass situation you may have some visual effects and some grass reduction. However, your much better off to put something with Simazine that will give you the opportunity to control the prennial vegetation. If you are going to spray bands and then plant into the bands, Dalapon and Simazine is a very cheap treatment. Dalapon is only about $1.70 a pound. You can put on ten pounds of it and control quack grass and fesque for baiscally the same price as 4 pounds of Simazine.

Question: How can black knot fungus be controlled on black cherry?

Answer: (Harvey Holt) I suspect with a chainsaw. That's a pathology question, I don't know.

Question: What chemical is best for controlling leafy spurge?

Answer: (Harvey Holt) The work being done on wiping applications of Picloram has been affective on leafy spruge. I would make the assumption that Roundup would probably be effective. Most of our experience with Roundup is in a wiping situation. Most our experience with wiping has been with the product Roundup because we control both grasses and broadleaves. The growth regulators, Picloram, Triclopyr; if you are just looking at a broadleaf situation, they are very effective.

Question: Do you know what the EPA regulations are on tank mixtures of Roundup and Simazine on fall application for site prep and establishment the following spring?

Answer: (Harvey Holt) I'm not sure about the EPA regulation, but Roundup is labeled for tank mixtures of Roundup and Simazine. It primarily relates to no-till corn. If neither one of the labels specifically prohibits the combination, and if you do not exceed the label rates of either product, it is not a misuse of the materials to apply them in a tank mix.

Question: How can you get plans for a home-built wick applicator?

Answer: Well, I would assume that your Cooperative Extension Service would have these sorts of things. Actually, the easiest way is to go down to the local Co-op and I suspect that near the Roundup display you will have all kinds of information on wick applicators. Monsanto has a couple brochures that basically describe what they look like and where you can get them. I've not seen them advertised, but I know they were looking at a promotion that if you bought a case of Roundup you got enough of the rope and the materials to make about a 10' boom.

Question: In the treatment of the stand where you treated all species except the oak and walnut, why did the oak go from 500 ft. per acre to 183 ft. per acre?

Answer: (Harvey Holt) I think the major reduction there, if you noticed, was that there were a large number of stems in that 0-2 ft. class. We did not coppice those, we just sprayed. Under the premise or assumption that those are probably so small that they are basically 2-3 year old seedlings they don't have much of a root mass. They are not the ones that we are really interested in saving; although obviously you could. The ones we were particularly interested in were those that were in that 2-6 ft. range, assumming that this is up in the order of this 4½ ft. size class that Paul has identified that we are really interested in for advanced regeneration.

Question: What is the minimal plot size for plot experiments? Can you apply herbicides uniformly on small plots?

Answer: (Harvey Holt) As a matter of fact, the smaller it is, the easier it is to apply uniformly. I don't quite know--you see plots in the agronomic area that are 40 inches wide and 6 feet long. Some

of our work is whatever you need in terms of a boom width; however, it needs to be long enough so that you can get enough plants in the plot--enough material to feel comfortable with the results.

Question: There were several questions about the labeling process, Harvey. One said, "Please discuss the reasons why some herbicides you mentioned are not labeled specifically for forestry use, and what can be done to get more of them labeled for plantation establishment?

Answer: (Harvey Holt) For some of the products, and let me address one in particular, Amazine. It has several hardwood uses, several species listed on the label, but it doesn't have black walnut. This is an old product, it has been around for several years. Talking with Union Carbide a few years ago, about why they didn't have walnut on the label; Amitrole, one of the active ingredients, is also one of the products that was involved with a cranberry problem several years back associated as a carcinogen. Basically at that time there were no new registrations being done with Amazine whatsoever. Consequently, walnut and Amazine have gone together since the early 60's. Then when we reached the stage in 1972; if it is not on the label you can't do it, then walnut was not there. Some companies are interested in expanding labels, particularly if it is a new product. If it is a proprietary compound, they can increase sales and generate some more income. That's not to be derogatory. But, you look at the new products, the Roundup label for example, they must issue 4 or 5 new labels a year. It just keeps getting bigger and bigger as they keep developing more uses--because, there is some monetary motivation there. Some of the older products, I doubt that we would see very much in the way of a change in the label. There is this aspect of a Section 24C, a state label, a special local need. And, some of the companies are responsive to basically adding these sorts of label uses. Now you really do need the company support, or at least the company blessing to use a product in that manner. In Illinois there is a 24C labelling for the combination of Atrazine and Simazine for black walnuts.

OPEN FIELD PLANTING

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The very title of this talk may be a misnomer at this time. It implies simple techniques, easy planting sites and large scale plantings. This type of planting site, especially for hardwood does not exist today. Our unique topography in this unglaciated portion of the country offers many challenges, and I might add, some unique planting opportunities.

Most of our soils are loams and clay loams which are excellent sites for trees. These fertile soils are also highly in demand for all agricultural use except for some of the steeper slopes. The topic, by it's very nature, will also include briefly some important points brought up by the other speakers. This should only highlight their importance.

I've had the opportunity to remain in one county for over 20 years. During this time I have assisted in planting 3½ million trees of which approximately 150,000 were hardwoods. This has also been the time of complete reversal of traditional tree planting techniques. Without some rather radical adjustments the past 10 years many recent plantings would have been complete failures.

Our early plantings were primarily conifer seedlings planted at traditional 6 foot by 6 foot spacing. The only site preparation was scalping of the sod. The heavier the grass competition, the deeper the scalp. On sandy soils and old field sites this technique worked quite well. In fact, several thousand acres of conifers were successfully established in western Wisconsin during the soil banks years of the late 1950's and early 1960's. Most of these have now reached commercial size and are being thinned. On heavy soils, deep scalps presented many problems. Tree roots were located in clay subsoil, heavy grass competition developed the first year and smothered the seedlings.

The old sandy field sites are mostly gone. We are now planting steep lands and heavy soils. Where possible, herbicides are applied prior to planting. Trees are slit in on the contour at 8 to 10 foot spacing. Some steep lands are slit in with transplant trees with very little soil disturbance.

The next step was planting of hardwood seedlings. Most of the slides are of black walnut, since it is a sentimental tree and has potential for high value. However, the same principles apply to other hardwoods.

Our first walnut seedlings became available from Wisconsin State Nurseries in 1966. Information on hardwood planting at that time was scant or non-existant. We were fortunate to have some excellent sites to work with. To reduce sod competition the fields were plowed the year before, planted to corn and treated with Aatrex. We assumed some herbicide carry-over so the site was not treated the first year. The trees were slit planted at 8 foot by 8 foot spacing. Alternate rows were planted to blue spruce and white pine. The intent was to remove every other row for Christmas trees and nursery stock.

Unfortunately, at agricultural rates there was very little herbicide carry-over. Giant rag weed came up in late summer and grew to a height of over 8 feet. Since it was impossible to locate the rows, site was broacast treated with herbicides the following year. The walnut responded well and dominant trees were over 6 feet in height after the third growing season. For the next four years herbicides were applied in 4 foot bands over the walnut.

A lot of problems developed with this planting arrangement. Although white pine does well on this site, there was a considerable amount of mechanical damage to white pine for Christmas trees from driving over them with a sprayer for 3-4 years. Since the primary objective was to grow walnut, the Christmas trees received very little attention. After 6 years approximately one-half were harvested, the rest were left. They are now making good trainers. Most of the blue spruce was sold for nursery stock and produced some early financial return to the landowner.

All was not wasted. Although recommendations at that time called for essentially pure walnut stands we decided to leave the white pine at this wide spacing to fill in between the rows. Our intent was to wait approximately 20 years and then commercially remove the white pine for pulp. Whether by accident, or by design, on this site it seems to be working quite well. At age 16 the walnut growing with some side competition from white pine has considerably better form than those growing in the pure stands. Although the diameter is slightly smaller they have the same height and much smaller branches. Self pruning is now quite evident.

Many mechanical and chemical site preparations are available--however, detailed information on their relative effectiveness, singularily or in combination for specific sites is lacking. In most cases we are using chemicals and equipment designed primarily for agricultural use.

I'm going to take you through the development of a couple other hardwood plantations to point out some main problem areas.

The next planting was designed to eliminate the problems with Christmas tree production, reduce spraying cost and improve efficiency. These fields had been in soybeans the previous years and treated with herbicides so vegetation was very light. We blocked most nozzles on the sprayer and sprayed two bands 4 feetwide, with approximately 16 feet between the rows. Spraying was done about two weeks before planting. This worked quite well and the bands were readily visible for planting and spraying for the next 4 years.

This operation was a success, but the patient died. After five growing seasons it became quite obvious that something was seriously wrong. This valley site with recommended site preparation, should be ideally sited for hardwoods. Soil type is listed as Fayette silt loam. These soils are generally deep, well drained loam soils with well over 4 feet to bed rock.

In the spring our entomologist examined the site and discovered some pecan case bearers in terminal buds. It was assumed this was causing the multiple tops and poor form and eventually the trees would grow out of it. No control was recommended at that time.

Later, a surplus of white pine transplants became available from another planting job so it was decided to make an 'insurance planting'. White pine transplants were slit in between the rows at 8 foot spacing. The objective of this recommendation was if the walnut didn't make it, the white pine would. This would assure complete utilization of the site.

Last year the areas of pure walnut were examined again. Mortality is now nearly 100 percent. The few live trees remaining are in very poor condition. Remaining areas will be interplanted with pine this spring. Some walnut, where interplanted with white pine have recovered and show some potential to develop. The row planted next to the field edge with some side competition also shows some potential.

The exact cause of this decline is not known but it appears to be site related. Our black walnut specialist will examine the area this spring to see if he can pinpoint the problem. Soil type maps may not be precise enough to identify micro-site requirements. A series of soil borings in walnut plantations last fall revealed in most cases where the decline occurred, soil mottling occurred within the root zone.

Another factor that seems to be very consistent is soil compaction. This could be from former agricultural use, soil type and slope location. The next 4 slides are in the same plantation. Elevation difference from bottom to top of slope is less than 50 feet. As we go up the slope the trees get progressively smaller. Where there is change in use from former agricultural crops to pasture, the effect is even more dramatic. Although the soil type as mapped is the same in this plantation, the 10 year growth pattern of different species is very revealing. Since both white pine and white spruce prefer soils similar to walnut for best development, soils obviously aren't the only limiting criteria. White pine and white spruce have both done very well on upper slopes and have a site index of 75-80. Soil compaction does not present the same problem in conifers.

Good hardwood sites are also excellent sites for all other weed trees and shrubs. A big problem, especially with wide spacing is control of other woody vegetation. Some side competition from weed species may be desirable to improve form. Cultural work will also be necessary in most stands to maintain rapid growth rate and improve form. On suitable sites, once established, the walnut will be very competitive.

Of all the hardwoods planted, I have yet to see a successful plantation established on good sites where some type of vegetation control was not completed. On medium to poorer sites, some trees survive for many years, but growth is slow and they are usually crowded out by inferior species. Interplanting forest soils is marginally successful with some species and will be discussed by the next speaker.

Not all hardwoods will be planted on good sites. They can be planted on heavy ridge soils, but growth and development will be considerably different.

On an old field site planted with walnut at 8 foot by 12 foot spacing in 1973, (nine growing seasons) some indication of future growth and quality has now become evident. The soil is listed as deep phase Dubuque which is

a clay loam. It received the 'silk glove' treatment for 5 years following planting. Herbicides were band sprayed and some mowing was done between the rows. Average height is now about 8 feet. At a growth rate of one foot a year, it will be a long time until this stand reaches sawlog size.

Whether or not this site will produce quality timber is quite speculative at this time. Probably the most one could expect would be an 8'-16' quality log and some sawlogs in the tops in 60-80 years.

With present land values, planting costs and the cummulative effect of taxes, obviously planting hardwoods on a site like this would be a very poor financial investment. Fortunately, most people and agencies that plant trees have more than financial return in mind. Otherwise, it is doubtful if anyone would be planting at today's interest rates. To compound a $5.00 per acre per year tax rate for 80 years would make your banker shudder. Even $1.00 per acre per year at 15 percent interest amounts to thousands of dollars.

We are often asked to modify our basic recommendations to meet an individual landowners objective. In many cases, this can be done without completely losing the primary purpose. We have combined a row of flowering crab apples for aesthetics with Christmas trees for early financial return and still have potential walnut stand. This may be a bit more intensive than most landowners will be able to manage. However, it can be done with some sacrifices. The walnut were slit planted, and treated with herbicides for 3 years. Balsam fir were then planted between the rows. Grass control helped the balsam get started and now has returned several hundred dollars per acre to the landowner. Finally, in spite of being on the edge of walnuts natural range, we do have some plantations that show much potential.

As a brief summary:

1. Weed control is essential to the successful afforestation of good sites on old fields with quality hardwoods.

2. Site selection is critical especially for black walnut, and is probably the most limiting factor.

3. Ridge type plantings are marginal even under the best conditions. If financial return is the main objective, these sites should probably be planted to conifers.

4. Some intermediate cultural work will be necessary on most good sites to remove invading inferior hardwoods and improve quality.

5. There is no one single factor that will guarantee success for failure.

HARDWOOD INTERPLANTING IN THE UPPER MISSISSSIPPI VALLEY

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Many upland forests in the Upper Mississippi Valley fail to adequately regenerate after overstory removal. This is particularly true of the region's oak (Quercus spp.) forests, which often do not have sufficient oak or other desirable reproduction to assure adequate stand development after overstory removal (Johnson, 1976b). Regeneration failures may also occur where stands have been high-graded so that there are inadequate seed sources of desired species. In either case, the regeneration problem is potentially solvable by interplanting.

WHAT IS INTERPLANTING?

Interplanting is defined as "setting young trees among existing forest growth, planted or natural" (Ford-Robertson, 1971). Consequently, interplanted trees must compete with natural forest vegetation that is continually changing because of growth and mortality. From a management perspective, this natural vegetation may consist of both desirable and undesirable tree species, shrubs, and herbaceous species.

WHERE TO INTERPLANT

Two factors largely determine conditions that justify hardwood interplanting: (1) the absence of "adequate" advance reproduction of desirable species, and (2) site quality.

Evaluating Site Quality

Site quality can often be assessed by using available site index curves. If stand site index based on site curves for northern red oak (Quercus rubra L.) is 60 ft (18.3 m) or greater, the site will generally be suitable for planting a variety of hardwoods, including some species that are more site demanding than oak. However, site index curves may not always provide a reliable measure of site quality. This is true where stands have been high-graded and where poor quality residual stems may underestimate the site's productive capacity. On the other hand, site quality may be overestimated if site index is estimated from red oak stump sprouts (Johnson, 1975). These situations require a site evaluation method that is independent of trees growing on the site.

One such measure of site quality is the topographic site coefficient (TSC) (Johnson, 1975, 1976a; Johnson and Rogers, 1980). TSC was developed to assess site quality in upland forests in southwestern Wisconsin and southeastern Minnesota. It is applicable to a wide range of topographic conditions where soils are sandy loam or finer. Using this method requires the following measurements: (1) soil plus parent-material depth to bedrock to a maximum of 50 inches (127 cm), (2) aspect (degrees azimuth), (3) slope position (upper, middle, or lower), and (4) slope percent. TSC can then be calculated from these measurements (Appendix 1).

TSC values range from 0.1 (poorest sites) to 1.0 (best sites). Although the relation between TSC and site index has not been established, the TSC range approximates the site index range of 40 to 70 ft (12.2 to 21.3 m) for northern red oak based on the curves of Gevorkiantz (1957). Sites with TSC values of 0.40 (average) or greater should thus be suitable for hardwood interplanting. Other methods for evaluating site quality of upland forests in the Upper Mississippi Valley are also available (Einspahr and McComb, 1951; Gevorkiantz and Scholz, 1944; Youngberg and Scholz, 1949; Wilde et al., 1948); however, in practical usage these methods may be less satisfactory than TSC when direct determination of site index is not feasible.

Evaluating the Need to Interplant

In some stands, evaluating the adequacy of advance reproduction and thus the need for interplanting may be a problem. Although guidelines for evaluating natural regeneration potentials are available (Sander et al., 1976; Marquis et al., 1975), they may not apply to Upper Mississippi Valley forests. Nevertheless, evaluation criteria should consider number, size, and spatial distribution of desirable advanced reproduction. If advance reproduction is judged inadequate, the contribution of expected stump sprouting can be used to compensate for this deficiency. For example, northern red oak is a prolific stump sprouter up to 100 years of age (Johnson, 1975; Wendel, 1975). The combined potential of advance reproduction and stump sprouting can thus be used to determine the total natural regeneration potential.

However, most of the oak stands in the Upper Mississippi Valley fail to produce adequate restocking of desirable species. Twenty-five years after oak stands were clearcut on average sites, oaks in the upper crown stratum average only about 80 trees per acre and few other desirable species are present (Johnson, 1976b). If we assume these 80 oaks average about 5 inches (12.7 cm) d.b.h., they will occupy only about 22 percent of "B" level stocking based on Gingrich's (1967) stocking criteria. The potential for interplanted hardwoods as a supplement to natural reproduction is thus apparent.

We should also recognize situations where interplanting is not indicated. Where stands have a significant sugar maple (Acer saccharum Marsh.) or white ash (Fraxinus americana L.) component, abundant natural regeneration may be obtainable by shelterwood cuttings (Godman and Tubbs, 1973; Marquis et al., 1975). In these stands, the shelterwood system should be tried using established guidelines before interplanting is attempted. Applying the shelterwood system may also increase the amount and size of advance oak reproduction (Johnson and Jacobs, 1981). Interplanting is not feasible in stands with a substantial aspen (Populus spp.) component. Planted trees are unlikely to successfully compete with the more rapidly growing aspen.

WHEN TO INTERPLANT

Interplanting can be done either before or after overstory removal. In either case, our discussion will assume that even-aged management will be applied and that overstory removal will be complete at the end of the rotation, i.e., all stems greater than 2 inches d.b.h. will be cut. Whether to plant before or after harvest cutting is a decision that remains. We'll consider these alternatives separately.

Interplanting After Complete Overstory Removal

If hardwoods are to be planted in clearcuts, planting should be done in the spring after harvest cutting, and harvest cutting should be done during the dormant season. During the first growing season after clearcutting, clearcuts are relatively favorable environments for planted trees because soil moisture and light are moderately high. Thus, if planting stock is of good physiological quality and adequate size, it can get off to a good start the first year.

Site preparation. Applying herbicides can further increase planting success. The type of herbicide to use will depend on the nature of the competition. Annual weeds are often a major component of the competition during the first 2 years after clearcutting, but by the third year woody competitors usually dominate. Some sites, particularly those that have been recently pastured, may have a sod cover that can seriously compete with planted hardwoods. These problems can be reduced by applying a herbicide that is effective against a specific target species. For example, on our research plots in Missouri we have found that Princep 80W [1/] is an effective pre-emergent herbicide for controlling annual weeds, Tordon 101R [1/] is effective in preventing sprouting when applied to stumps of unwanted species, and Roundup [1/] is effective for controlling certain grasses and herbaceous weeds. Use of herbicides in hardwood forest planting has been further discussed by Holt et al. (1981).

Although the effectiveness of one herbicide application in reducing competition is likely to be temporary, the impact on planted trees may nevertheless be significant. Trees that grow slowly during the first year in the field are usually doomed to permanent suppression. Conversely, a rapid start will enable a substantial proportion of interplanted trees to become "successful" competitors even when severe competition develops in succeeding years.

How many trees of what species should we plant? To help answer this, we can look at data collected from a stand in Green County in southern Wisconsin for which we have 16-year data on five hardwood species interplanted in an oak clearcut (oak site index about 60 ft (18.3 m)).

[1/] Mention of trade names does not constitute endorsement of the product by the U.S. Department of Agriculture, Forest Service.

After 16 years the percent of planted trees (1 + 1 stock) that were codominant-or-larger ranged from 10.9 percent for American basswood (Tilia americana L.) to 38.5 percent for red maple (Acer rubrum L.) (Appendix 2). White ash and sugar maple also grew relatively well; slightly more than one-third of the trees attained codominant-or-larger status. Thus, if these results are representative, we would need to plant from 2.6 to 2.8 of the best performing species (maples and white ash) to obtain one codominant-or-larger tree 16 years after planting.

If we wanted to be more confident of planting success, we could estimate how many trees we'd have to plant to obtain, with a probability of 0.8 or greater, one codominant-or-larger tree 16 years after planting. This would increase the number of trees we'd have to plant, but would better assure us that we'd attain our goal at least 80 percent of the time. These estimates are presented in Table 1 and are expressed as numbers of trees that must be planted to obtain at least 100 codominant-or-larger trees 16 years after planting. Maples and white ash require 331 to 372 trees per acre. The requirement for other species is substantially higher, ranging from 448 for yellow-poplar (Liriodendron tulipifera L.) to 1,394 for American basswood. However, better growth of American basswood has been observed in a Canadian study (Stroempl, 1971); 4 to 7 years after planting, about 30 percent of trees interplanted in hardwood "cutovers" were judged potentially capable of becoming part of the future main stand.

Based on their performance in this study, the two maples and white ash appear to be the best hardwoods to interplant in the region. However, we do not know what proportion of surviving trees will maintain or improve their present crown position. Over the last 8 years, the proportion of upper-stratum white ashes has remained essentially unchanged; however, an average of 6 percent of the maples dropped out of the upper stratum, or 0.75 percent per year. We also don't know the effect of pre-commercial thinning on the planted trees. Obviously, we need longer term data on dropout rates to determine how many of the present upper strata trees will maintain their crown positions to rotation age in both thinned and unthinned stands.

Although the results of interplanting northern red oak in this study were disappointing, better results have been reported in a West Virginia study (Wendel, 1980). In that study, 30 to 50 percent of interplanted 2 + 0 seedlings were judged successful after 7 years of growth in clearcuts indicating that 2 to 3.3 red oaks would have to be planted to obtain 1 successful tree. This compares favorably with the results of sugar maple and white ash interplanting in the southern Wisconsin study. Although differences in climate may explain different study results, physiological quality of planting may also be a cause of differences as will be discussed later.

Interplanting yellow-poplar in the Upper Mississippi Valley will be risky because the region is well outside this species' natural range; mortality from frost may be severe in some years. We also need more interplanting trials with American basswood, red oak, and black walnut (Juglans nigra L.) to better ascertain their potential in artificially regenerating upland clearcuts in the region.

Table 1.--Estimated number of trees that must be planted in an upland clearcut to obtain, with a probability of 0.8 or greater, at least 100 codominant-or-larger planted trees after 16 years 1/

Species	Trees per acre to plant 2/	Expected mean d.b.h. of codominant-or-larger trees 16 years after planting	Maximum growing space utilizable per 100 codominant-or-larger trees
	-Number-	-Inches-	-Percent- 3/
Red maple	331	4.5	18.7
White ash	354	3.1	16.9
Sugar maple	372	3.6	16.4
Yellow-poplar	448	5.3	25.4
Northern red oak	782	3.2	14.5
American basswood	1394	4.1	11.1

1/ Based on 91 to 126 1+1 transplants of each species planted in an oak clearcut (upland oak site index 60 ft (18.2 m)) in Green County, Wisconsin. Trees were planted in April 1966 after winter cutting of all trees 2 inches (5 cm) d.b.h. and larger; no weed control was used (Johnson, 1976a).

2/ Method of calculation is given in Johnson, 1976a.

3/ This is the maximum percent of an acre that 100 interplanted trees of a given mean diameter could utilize (i.e., a percent of "B" level stocking). The maximum spatial utilization of northern red oak is based on the given expected mean d.b.h. (3.2 in (8.1 cm)) and Gingrich's (1967) maximum tree area equation that defines "B" level stocking; all other species are based on Roach's (1977) tree area equation and 60 percent stocking (aproximate "B" level) and the given expected mean d.b.h.

Underplanting With Subsequent Overstory Removal

An alternative to interplanting hardwoods in clearcuts is to underplant in mature stands. This may allow the root systems of the planted trees to become well established before competition peaks after clearcutting. Underplanting also eliminates the difficulty of planting in the logging slash created by clearcutting. However, to be successful, both overstory and understory density control may be required to produce the light and soil moisture conditions necessary for adequate development of planted trees before the final harvest cut. Underplanting therefore has much in common with the shelterwood method of natural regeneration (Sander, 1979).

The success of naturally regenerating sugar maple under shelterwoods (Godman and Tubbs, 1973) with the maple's shade tolerance, suggests that this species is the logical choice for underplanting. Similarly, the successful development of advance oak reproduction under certain stand conditions indicates that underplanting may be a more natural method for artificially regenerating oaks than planting in clearcuts. Unfortunately, little information is presently available on underplanting of hardwoods.

In a Missouri study, we measured height growth and survival of northern red oaks underplanted in mature stands and also interplanted in clearcuts. In this study we removed the overstory from the underplanted plots between the third and fourth growing seasons after planting. The classes of nursery stock planted included large 1 + 0 seedlings, small 1 + 0 seedlings, and 1 + 1 transplants. Within each class of nursery stock, we clipped the tops of half of the seedlings 6 in (15 cm) above the root collar just before we planted them in the fall. We measured seedling height before and after the fourth growing season and calculated fourth-year net shoot elongation as the differerence between the two height measurements.

Among the underplanted trees, the 1 + 1 clipped trees grew fastest the first year after overstory removal: 38.5 percent increased their height by at least 16 in (40 cm) 2/ (fig. 1). This percentage was not statistically different from 1 + 1 transplants that had been interplanted in the clearcuts 3 years previously. These results are noteworthy for two reasons: (1) we have not previously observed that great a percentage of planted oaks growing that fast their first year in a clearcut, and (2) because the clearcut-planted trees were larger than the underplanted trees at the beginning of the fourth growing season (Appendix 3), we might have expected the clearcut-planted trees to have outgrown the underplanted-released trees in the fourth year.

2/ This growth criterion (16 in/40 cm of net shoot elongation) was selected because it approximates the average net shoot growth of dominant woody competitors in young clearcuts on similar sites.

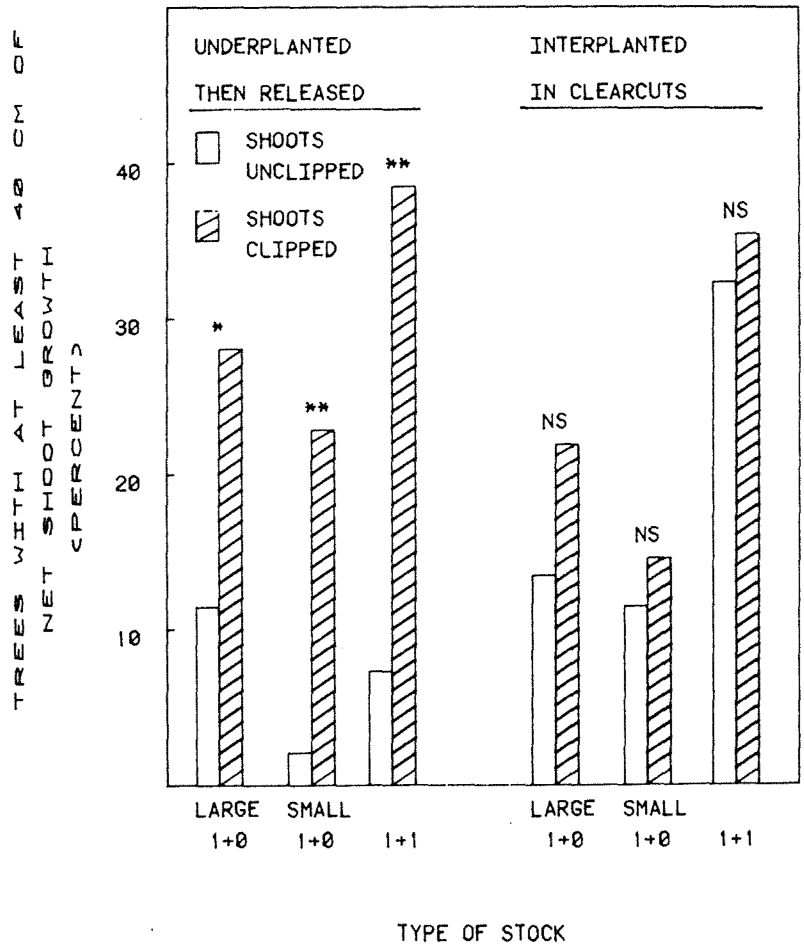

Figure 1.--Percent of planted northern red oaks with at least 16 in (40 cm) of net shoot growth after their fourth field growing season. (Underplanted trees were released from the overstory between the third and fourth growing seasons. Significance level of differences between each treatment-pair of clipped and unclipped trees is based on chi-square: * = .05, ** = .01, and ns = non-significant. Other data for this study are presented in Appendix 3).

Why the clipped trees outperformed the unclipped trees in the underplanted-released plots the fourth year is not clear. However, we speculate that this may be related to a higher root:shoot ratio of the clipped stock. If this proves to be the case, success in underplanting might depend on the development of relatively high root:shoot ratios before overstory removal. The apparent growth advantage of a high root:shoot ratio is observable in the rapid shoot growth of oak stump sprouts (Johnson, 1975, 1979; Wendel, 1975). However, an apparently higher root:shoot ratio did not benefit the clipped trees that were interplanted in the clearcuts. These early results suggest that underplanted oaks can increase the size of their root systems in an understory, even though shoot growth may be negligible during the time trees are in the understory. Despite the good fourth-year growth of clipped trees, total average height of unclipped trees was nevertheless still greater than that of clipped trees 4 years after planting (Appendix 3).

There is probably an optimum length of time underplanted oaks should remain in the understory before they are released. Over long periods, mortality of underplanted trees will probably begin to outweigh any growth advantage that underplanting might have provided. It nevertheless seems likely that at least 2 or 3 years will be required before an underplanted oak will substantially increase its growth potential. Different species may also have different optimal understory establishment periods. It is therefore necessary to expand our experience in hardwood underplanting before more definite recommendations can be made on nursery stock requirements and developmental probabilities for different species.

QUALITY OF NURSERY STOCK

Quality of planting stock can determine success or failure of hardwood interplanting. Quality includes not only the size of stock, which may differ by species, but also the physiological condition of the stock at time of planting.

Size of Nursery Stock

Based on our and other studies (von Althen and Webb, 1980; Farmer, 1975a), the following nursery stock size (grade) standards are suggested for hardwood interplanting in the Upper Mississippi Valley. For sugar and red maple, minimum shoot length should be about 6 inches (15 cm) with an average of no less than 10 inches (25 cm), and a basal caliper (measured 1 inch (2 cm) above the root collar) of at least 3/16 inch (5 mm). White ash and northern red oak should have shoot lengths of at least 20 inches (50 cm) with a minimum caliper of 5/16 inch (8 mm). Growing stock to this size will probably require at least two growing seasons in most nurseries within the region. For comparison, the present hardwood grade standards for five nurseries in the region are given in Appendix 4.

In our studies to date, 1 + 1 red oak transplants have outperformed 1 + 0 seedlings even when the 1 + 0 seedlings were larger than the transplants (Johnson, 1979). However, in a West Virginia study, 2 + 0 red oak survived and grew well (Wendel, 1980) as did 2 + 0 and 3 + 0 sugar maple in abandoned fields in Ontario (von Althen and Webb, 1980). Some of the advantages observed with 1 + 1 oak transplants might also be obtainable by undercutting seedlings in the nursery bed. We're now evaluating this technique for producing better quality northern red oak and white oak (*Quercus alba* L.).

Physiological Quality of Nursery Stock

Hardwood nursery stock of the size outlined above has the potential for relatively rapid shoot and root development (Farmer, 1975b; Johnson, 1979). Unfortunately, even with large stock, this potential has not always been realized in forest planting. Recent research has indicated that poor physiological condition of nursery stock may be the cause of these failures.

The dormancy environment. Physiological condition of nursery stock at time of spring planting is greatly influenced by the dormancy environment that immediately precedes planting. Nursery stock may be fall-, winter-, or spring-lifted. In the latter case, the dormancy environment is the nursery bed in which the stock was raised. For fall-and winter-lifted stock, the dormancy environment includes a period of time in a cold storage room or a heeling-in bed. Physiological deterioration of hardwood nursery stock can occur in all of these environments.

Recent research on cold storage of hardwoods has shown that fall-lifted and cold-stored stock can perform as well or better than spring-lifted stock (von Althen and Webb, 1981). For white ash, American basswood, northern red oak, and sugar maple, the optimum storage environment is about 0.5° C coupled with 70 to 85 percent relative humidity; in contrast, black walnut required a 5° C storage temperature. Performance of spring-planted stock of all species tested was reduced when storage temperatures were 5° C above or below these apparent optima.

How stock is packaged during cold storage is also important. A recent study has shown that the best results were obtained by enclosing the entire seedling in a Kraft bag with a polyethylene liner (Webb and von Althen, 1980). The addition of wet peat to the bags had little effect on sugar maple seedling survival or growth (von Althen and Webb, 1980).

Fall-lifting, combined with proper cold storage and packaging can extend the planting season. In Ontario, the planting season for cold-stored sugar maple could be extended into June. In contrast, good height growth and root regeneration of spring-lifted seedlings was obtained only for seedlings planted before the middle of May (von Althen and Webb, 1978). For black walnut, the best field performance was obtained by lifting no earlier than 1 month after leaf fall and no later than the time of spring bud swell (Rietveld and Williams, 1981).

Although spring-lifted stock may perform as well as fall-lifted and properly cold-stored stock, trees left to overwinter in the nursery bed are subject to the vagaries of winter weather. Stock overwintered outside may not always receive adequate chilling during a mild winter, particularly in nurseries in the southern part of the region (Rietveld and Williams, 1981). Conversely, extremely cold winters may fail to optimally satisfy the physiological chilling requirements of the nursery stock. Optimum temperatures for breaking bud dormancy in most woody plants range from 1° and 10° C and extremely low temperatures may retard dormancy release (Samish, 1954).

Deterioration of hardwood stock left in the nursery bed to overwinter was observed at the Wisconsin State Forest Nursery at Boscobel, with winter desiccation the suspected cause. 3/ Similarly, we have observed shoot dieback in hardwoods that have been heeled-in at the State Forest Nursery in Missouri. Because of relatively poor root-soil contact and reduced root surface area, effects of winter desiccation may be more severe in heeling-in beds than in nursery beds. Soil warming during prolonged warm periods may cause premature breakage of dormancy (Williams and Hanks, 1976); under these conditions premature root growth may also be a problem with sugar maple (von Althen and Webb, 1980). Because both shoot dieback and frost heaving may occur in fall planted stock, spring planting is recommended. In oaks, the consequences of winter shoot dieback include reduced and delayed root growth capacity and reduced shoot growth (Johnson, 1979).

The cause of winter shoot dieback is apparently linked to bud viability rather than the shoot *per se*. Substances translocated from viable buds during late winter influence the initiation of cambial growth and thus the formation of the new growth ring (Wareing, 1951). Because most, if not all, water transport in the stem of ring porous species (e.g., oaks and ashes) occurs in the new ring (Zasada and Zahner, 1969), the formation of the new water transport system (xylem vessels) in early spring can be seriously impaired when buds are not fully functional. Consequently, it is the physiological failure of buds that may account for much of the commonly observed winter shoot dieback in hardwood nursery stock of ring-porous and perhaps other species.

Buds also play an important role in the initiation of root growth in hardwoods (Lee *et al.*, 1974; Farmer, 1975a). Debudded pin oak (*Quercus palustris* Muenchh.) seedlings initiated only about one-fourth the number of roots that normal seedlings did (Lee *et al.*, 1974). Similarly, root growth was reduced when northern red oak and silver maple (*Acer saccharinum* L.) seedlings were debudded (Larson, 1978; Richardson, 1958).

Buds of dormant hardwood seedlings must therefore be protected against both physical and physiological damage during lifting, handling, and storage. Buds may also be damaged after the trees leave the nursery. This emphasizes the importance of completely enclosing nursery stock when packaging. Because methods of lifting, storing, and packaging hardwood nursery stock are essential to planting success, methods used in five nurseries within the region are summarized in Appendix 4. It is also essential to plant trees as soon as possible after receiving them from the nursery and to do so with proper field handling and planting technique.

3/ Personal communication, Richard Camp, Nursery Manager, F. G. Wilson Nursery, Wisconsin Department of Natural Resources, Boscobel, Wisconsin, January 18, 1982.

Other physiological factors. Physiological quality of nursery stock of some hardwood species can also be improved through the introduction of selected mycorrhiza into nursery beds (Dixon et al., 1980; Garrett et al., 1979). Methods are presently available for white oak, northern red oak, and black oak (Quercus velutina Lam.) (Marx, 1979a, 1979b; Dixon et al., 1981). Benefits of mycorrhizal infection may be futher enhanced by foliar fertilization in the nursery (Wright, 1979).

Using plant growth regulators on hardwood nursery stock is a promising means of getting root growth started before seedlings are exposed to moisture stress (Moser, 1981). Some of these growth regulators may also become useful in controlling or stimulating root and shoot growth in the nursery. Another futuristic advancement is the potential use of tissue culture to mass produce selected genotypes of hardwoods; the necessary micropropagation methods have already been developed for several tree species (Millikan and Gowin, 1981). All of these advances in tree physiology and genetics will eventually trickle down to practical nursery and field practice. The result may not only be faster growing trees, but more species to select from for hardwood interplanting.

SUMMARY AND CONCLUSIONS

Interplanting appears to be a feasible alternative to relying on natural reproduction to regenerate upland hardwood forests in the Upper Mississippi Valley. Interplanting may be most feasible as a supplement to natural regeneration. White ash, sugar maple, and red maple have shown promise in interplanting in clearcuts, provided that relatively large stock of high physiological quality is used. However, even with these species, three to four trees must be planted to assure the establishment of one codominant-or-larger tree 16 years after planting. To assess planting needs in any given stand, the potential contribution of advance reproduction and desirable stump sprouts should be evaluated together with site quality. Interplanting should be concentrated on the better sites.

Interplanting under mature hardwoods (underplanting) may be a feasible alternative to interplanting in clearcuts. As in clearcut planting, the possibilities for obtaining adequate natural reproduction should first be evaluated. Although information on hardwood underplanting is scarce, early results with northern red oak are encouraging. The first year after release from 3 years in the understory, about 3/8 of 1 + 1 red oak transplants with clipped shoots grew as fast or faster than their woody competitors. This proportion of trees was substantially greater than for oaks planted directly from the nursery into clearcuts. However, relatively large 1 + 1 transplants were needed to obtain this response.

In addition to proper species and site selection, success in interplanting depends on the quality of planting stock. Stock quality refers to both the size (grade) of nursery stock and its physiological condition at time of planting. Even with relatively large stock, a near-optimal dormancy environment must be maintained until trees are field planted. Cold-storge temperature, relative humidity, and method of packaging during storage are particularly important for fall-lifted, spring-planted stock. Heeled-in stock, and to a lesser extent spring-lifted stock, are subject to possible winter desiccation with attendant shoot dieback and loss of physiological vigor.

In the future we may expect advances in the physiological quality of hardwood nursery stock as a result of routine mycorrhizal inoculation of nursery beds and the use of foliar fertilization to further enhance the benefits from mycorrhiza. Other futuristic advances may involve the use of growth regulators to control or stimulate shoot and root growth in the nursery plus the development of methods for propagating selected genotypes of hardwood species by tissue culture. These advances could substantially augment the field forester's current bag of solutions to the problem of regenerating hardwood forests in the Upper Mississippi Valley.

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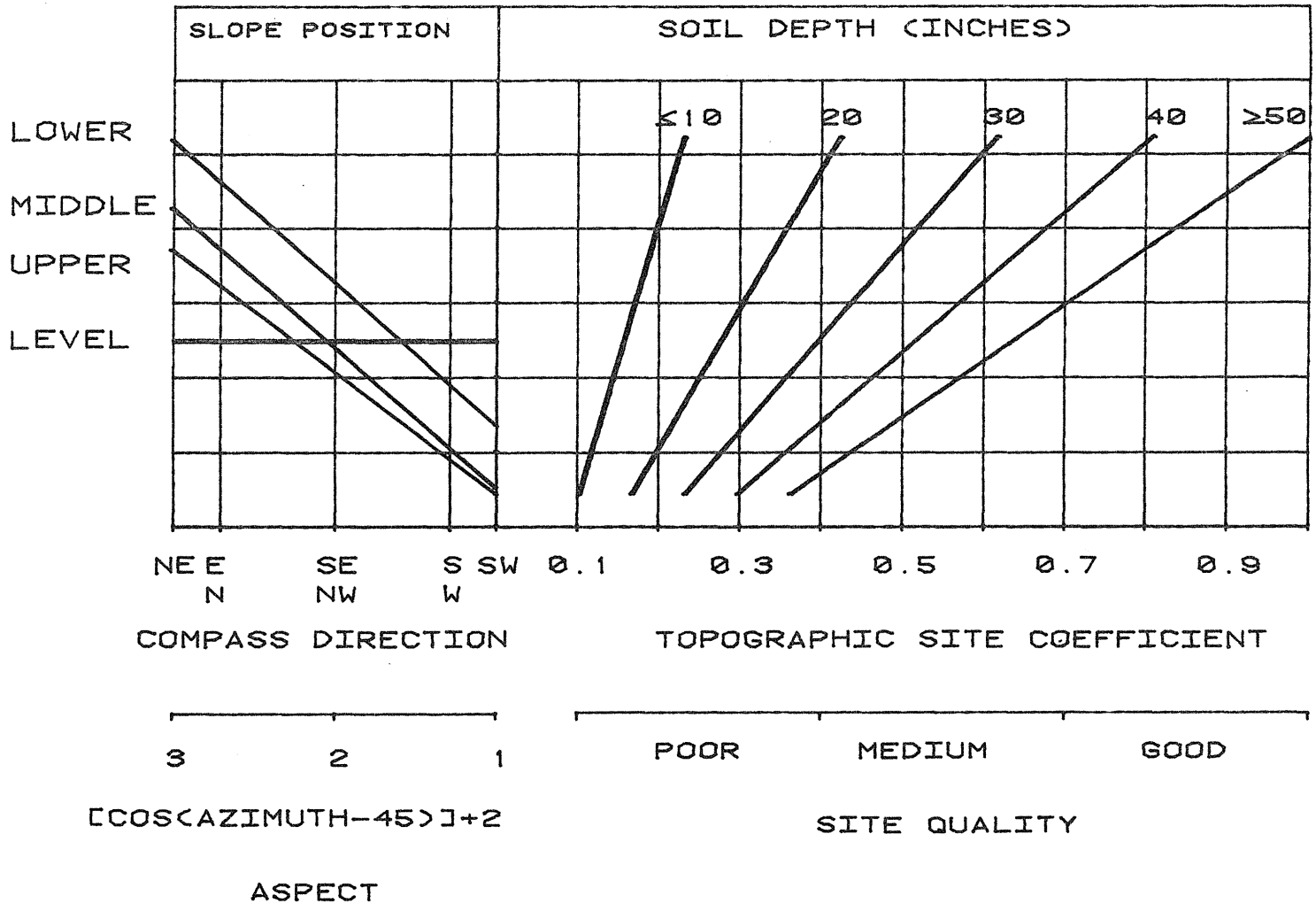

Appendix 1.--Relation between topographic site coefficient (TSC) and aspect, slope position, and soil depth. (To find TSC, locate aspect on transformed azimuth scale or compass scale. Then proceed upward until you intersect the appropriate slope position. Use the LEVEL line for level topography and all slopes less than 15 percent. Next, proceed horizontally to the right until you intersect the appropriate soil depth. Finally, proceed downward and read TSC value.)

Appendix 2.--Height, survival, and crown class attainment of 1 + 1 transplants interplanted in a southern Wisconsin oak clearcut [1/]

Species	Height at time of planting: Mean	Height at time of planting: Standard deviation	Height at time of planting: Trees planted	After 16 years: Survival	After 16 years: Height of survivors: Mean	After 16 years: Height of survivors: Standard deviation	After 16 years: Codominant-or-larger trees as a percent of trees planted
	-Inches-		-Number-	-Percent-	-Feet-		-Percent-
Red maple	10.5	4.0	91	78	28.6	13.7	38.5
White ash	27.2	6.2	126	94	23.6	8.2	36.5
Sugar maple	10.9	3.6	94	83	24.2	11.5	35.1
Yellow-poplar	16.8	5.4	96	51	29.9	13.8	30.2
Northern red oak	20.7	7.1	97	45	21.4	12.1	18.6
American basswood	10.6	3.6	92	57	13.2	11.1	10.9

[1/] Trees were planted in an oak clearcut (upland oak site index 60) in Green County, Wisconsin in April 1966 after winter cutting of all trees 2 inches d.b.h. and larger. No weed control was used.

Appendix 3.--Fourth-year heights, net shoot elongation, and survival of northern red oaks planted in clearcuts and underplanted in partially cut-released stands [1/]

Planting site	Type of nursery stock and shoot treatment	Before planting: Mean shoot length [2/]	Before planting: Mean shoot caliper [3/]	After 4 years: Survival	After 4 years: Mean height of survivors ± standard deviation	After 4 years: Mean net shoot elongation of survivors ± standard deviation
		cm	mm	Percent	cm	cm
Trees planted in clearcuts [6/]	1+0 large, unclipped	88.3	10.1	71.9	89.0±38.9	17.0±24.0 [5/]
	1+0 large, clipped [7/]	86.5	10.2	89.6 ** [4/]	76.8±42.2	24.9±21.6
	1+0 small, unclipped	48.2	8.3	83.3	80.1±31.8	18.8±19.8
	1+0 small, clipped	48.8	7.9	75.0 ns	66.0±32.2	21.6±17.1
	1+1 unclipped	53.8	10.1	87.5	102.5±48.0	34.3±31.1
	1+1 clipped	57.0	10.4	90.6 ns	91.6±45.7	32.2±25.2
Trees underplanted in partial cuts and released after 3 field growing seasons [8/]	1+0 large, unclipped	87.6	10.5	69.8	81.4±28.5	13.4±25.0
	1+0 large, clipped	89.3	10.3	92.7 **	62.0±24.5	30.1±23.6
	1+0 small, unclipped	47.1	7.9	74.0	56.1±24.2	6.6±18.6
	1+0 small, clipped	49.3	8.5	86.5 *	54.5±19.6	23.6±19.5
	1+1 unclipped	56.1	10.7	90.6	67.3±27.5	10.2±20.8
	1+1 clipped	54.7	10.3	93.8 ns	67.8±30.1	31.3±26.1

1/ Trees fall-planted on sites of northern red oak site index 19.8 to 22.9 m (65 to 75 ft) in southern Missouri; 96 trees were planted per stock type and shoot treatment combination in eight randomized complete-blocks.

2/ Length of shoot before clipping.

3/ Diameter 2 cm (1 in) above the root collar.

4/ Significance of difference between clipped and unclipped trees for a given type of stock is based on chi-square; * = .05, ** = .01, ns = non-significant.

5/ Shoot dieback may result in negative values of shoot elongation and hence large standard deviations in relation to the mean.

6/ Clearcuts were planted at the same time partial cuts were planted and before the onset of the first field growing season after clearcutting.

7/ Shoots clipped 15 cm (6 in) above root collar before fall planting.

8/ Partially cut plots were reduced to "B" level stocking (Gingrich 1967) before planting; overstory was then removed between the third and fourth field growing seasons after planting.

Appendix 4.--Minimum stock size, age class, and storage environment for selected hardwoods in five state forest nurseries serving the Upper Mississippi Valley

Nursery	Species	Minimum Height		Minimum Caliper		Age class	Lifting, storage, and packaging
		in	(cm)	in	(mm)		
State Forest Nursery, Iowa Conservation Commission, Ames, Iowa	Northern red oak	6	(15)	5/32	(4)	1+0	Lifting: Early November; 6-8 in (15-20 cm) depth. Storage: In poly bags in cooler at 34°-36° F (1°-2° C) until grading; after grading, put back into cold storage until shipping time. Packaging: 50-tree poly bags inside of completely enclosed Kraft paper bags.
	White oak	5	(13)	5/32	(4)	1+0	
	Sugar maple	6	(15)	5/32	(4)	2+0	
	White ash	8	(20)	5/32	(4)	1+0	
	Black walnut	8	(20)	5/32	(4)	1+0	
	Shagbark hickory	4	(10)	1/4	(6)	1+0	
Wilson Nursery, Wisconsin Dept. of Natural Resources, Boscobel, WI	Northern red oak	8	(20)	5/32	(4)	2+0	Lifting: Mid-October; 8 in (20 cm) depth. Storage: Healed-in in unmulched trenches until spring grading and baling. Packaging: Dampened 3-ply Kraft bag containing 250 entirely enclosed seedlings.
	White oak	8	(20)	5/32	(4)	2+0	
	Sugar maple	5	(13)	5/32	(4)	3+0	
	White ash	8	(20)	5/32	(4)	2+0	
	Black walnut	10	(25)	1/4	(6)	1+0	
	American basswood	8	(20)	5/32	(4)	1+0	
General Andrews Nursery, Minnesota Dept. of Natural Resources, Willow River, MN	Northern red oak	(no set minima)				2+0	Lifting: Early to mid-October; 8-9 in (20-23 cm) depth. Storage: Oaks healed-in in nursery bed or stored in cellar at variable temperature; walnut stored in poly-covered boxes at 26°-28° F (-2° to -3° C) until baling in March; put back into storage after baling until shipping time. Packaging: Double-end jellyroll bale using asphalt impregnated paper with moist spaghnum moss; 250 trees/bale.
	Black walnut					1+0	
Union Nursery, Illinois Dept. of Conservation, Jonesboro, IL	Northern red oak	12	(30)	1/4	(6)	1+0	Lifting: Beginning early December and throughout the the winter; 8 in (20 cm) depth. Storage: On carts in cold storage at 33°-34° F (.5° to 1° C); covered with moist spaghnum moss and burlap until shipping time. Packaging: Kraft 3-ply vinyl-coated bags containing 25-tree bundles; roots moistened; no moss.
	Yellow-poplar	8	(20)	1/4	(6)	1+0	
	White ash	12	(30)	1/4	(6)	1+0	
Mason Nursery, Illinois Dept. of Conservation, Topeka, IL	White oak	8	(20)	5/32	(4)	1+0	Lifting: Mid-November through mid-December and mid-March through April; 10-12 in (25-30 cm) depth. Storage: In variable temperature cool room in plastic bags for up to one week before grading; after grading put into 34° F (1° C) cold storage in jellyroll bales. Packaging: Jellyroll bale of asphalt-laminated paper with Con-wed non-woven fabric around roots; no moss; bales shipped in Kraft bags.
	Sugar maple	8	(20)	3/16	(5)	2+0	
	Black walnut	8	(20)	1/4	(6)	1+0	
	Hickory (mixed spp.)	2-6	(5-15)	1/8	(3)	1+0	

DIRECT SEEDING HARDWOODS IN THE UPPER MISSISSIPPI VALLEY

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Direct seeding has been around a long time, and for some species, particularly the southern pines, it is a proven and effective method of regeneration. For the hardwoods, however, direct seeding has met with less than spectacular success. Published information is meager and the results of studies have been highly variable. The oaks have been studied more intensively than any other hardwood species, but an effective, easily applied, and economically feasible way to direct seed them has yet to be developed. Studies conducted in Iowa, Wisconsin, Missouri, Tennessee, and North Carolina compared fall vs. spring seeding, protected vs. nonprotected seed, surface vs. in-soil sowing, and litter vs. no-litter covering (Krajicek, 1960; Scholz, 1964; Nichols, 1954; Mignery, 1975; Sluder et al., 1961). The only consistent trends that emerged from these studies were increased seedling establishment when the acorns were protected by screens and when acorns were sown 1-2 inches deep in the soil. Other general observations that can be made are that spring sowing in which only sprouted acorns were sown produced somewhat more seedlings than fall sowing, and a light litter cover appears to be beneficial, particularly for fall-sown acorns.

Good information on direct-seeding other hardwoods is scarce. Generally, trials with basswood and sugar maple have failed. Some success has been attained with white ash in Wisconsin, but results have been inconsistent.[1/]

Although results of direct-seeding studies have been mostly negative, there have been a few trials that were successful enough to indicate there may be some hope. What then are the prospects for successfully direct-seeding hardwoods in the Upper Mississippi Valley? Before we can answer that question, we need to look at the factors that influence the success of direct seeding.

SEED

Seed quality is very important. The germinative capacity of any particular seed lot must be known in order to determine a seeding rate that will potentially produce an adequate number of seedlings. Germinative capacity of different seed lots is highly variable and germination tests should be made on each lot. White oak is the only species of interest that does not have embryo dormancy. All the others must be stratified for 60-110 days before a germination test can be conducted. Basswood seed also has a hard seed coat that is impervious to water and should be treated with sulfuric acid before it is stratified (USDA Forest Service, 1974; Vanstone, 1978). For freshly collected seed, the stratification requirement precludes germination tests if fall sowing is planned. However, the percent of apparently sound seed in a collection can be quickly determined by cutting tests and will probably be adequate for fall sowing of freshly collected seed.

1/ Personal communication with R. M. Godman, North Central Forest Experiment Station, Rhinelander, Wisconsin.

As soon as it is mature, seed should be collected as close to the area to be seeded as possible. Seedlings from a local source will generally survive and grow better than those from a distant source, particularly if the distant source is very far north or south of the seeding area. Seed production of these hardwood species varies greatly from year to year and from tree to tree within a species. Basswood and sugar maple are more consistent producers than white ash and the oaks, but production is irregular enough that seed from local sources may not be available when needed (Godman and Mattson, 1975; USDA Forest Service, 1965). Of course, seed can be purchased if local seed is not available, but the source and germinative capacity should be known.

Another way to ensure an adequate seed supply for poor seed years is to collect more seed than needed in good seed years and store it. Except for white oaks, hardwood seed can be stored successfully but the requirements depend on the species (Table 1). After 1 year, stored seed will lose some viability and the longer it is stored the greater the loss, particularly for northern red oak. Thus, when seed is removed from storage for use, germination tests should be made.

SEED DEPREDATION

One of the most important factors affecting the success of hardwood direct seedings is seed pilferage by squirrels, mice, chipmunks, and birds. This is particularly true for the oaks and probably for basswood as well. Many repellents have been tried but none have proven successful. Mechanical protection with screens has worked best, but even these are not completely effective and they are expensive (Mignery, 1975). Poisoned baits have also been tried but with limited success (Shirley, 1937). Apparently rodents are able to quickly determine what is poisoned and what isn't. However, if direct seeding is to be a viable regeneration practice, controlling seed depredation is necessary.

Site preparation may be an effective way to control rodents. For example, a direct seeding of nuttall oak on a completely prepared forest site in Mississippi was successful; but in an adjacent site that received no preparation, rodents removed all acorns within a week after sowing (Johnson, 1981). Apparently the site preparation destroyed the habitat and the rodents simply left.

SITE PREPARATION

Good site preparation will increase the chances for direct-seeding success. For all species, germination is best in a mineral soil seedbed, although this is not critical for sugar maple (USDA Forest Service, 1965). Site preparation should not only prepare the seedbed, but it should also reduce competition from grasses, weeds, and woody vegetation at least for a couple of years.

The site preparation method to use will depend on the situation. Bulldozing or discing should be suitable on level or only slightly sloping terrain where erosion will be minimal or controllable. Prescribed burning may work, although there is no information on its effectiveness. A single burn should

be adequate to prepare the seedbed but will not effectively reduce competition. Herbiciding in combination with burning should be a viable site preparation method.

SOWING METHOD AND RATE

Broadcast sowing is not practical for direct-seeding oaks because of the large seed and the fact that acorns should be sown 1-inch deep in soil. Oaks should be spot-seeded or seeded in shallow furrows. Drilling may be feasible on certain sites if suitable equipment is available. These methods can also be used with other hardwood species.

Broadcast-seeding white ash, sugar maple, and possibly basswood may be feasible. However broadcast seed is subject to predation and excessive drying if precipitation is inadequate to maintain a moist soil surface. Fall sowing may be less risky from this standpoint than spring sowing. Chances for success when seed is broadcast are probably improved if the seed can be covered with soil. Covering the seed also makes it harder for predators to find. Light discing after seeding is a possibility, but it would also increase the cost. A larger area can be covered in the same amount of time by broadcast seeding than by the other methods, but larger amounts of seed are needed. We do not know if the time savings is a real advantage nor do we know the relative success of broadcast vs. other seeding methods.

Unfortunately there is no information available to indicate what seeding rates for the various hardwood species should be. However, the minimum amount of seed needed can be approximated if the germinative capacity or percent of apparently sound seed is known. For example, if a seed lot contains 70 percent apparently sound seed and 5,000 seedlings per acre are wanted, at least 7,142 seeds per acre must be sown. Somewhat more seed will probably be required because some seed will be eaten by animals or birds. Further, field germination may be less than that indicated by germination or cutting tests because these tests are not designed to determine how many germinated seeds actually produce seedlings.

SOWING TIME

The slight advantage spring sowing showed over fall sowing for oaks may not be real. In most studies only germinated acorns were sown in the spring but no information was presented about the germinative capacity of acorns sown in the fall. If the fall-seeding rates were adjusted according to germinative capacity, the advantage shown by spring seeding might disappear.

Spring sowing requires the use of stratified seed; seed sown in the fall undergoes stratification overwinter. For fall sowing, seed should be sown as soon after collection as possible. Basswood seed may germinate acceptably if collected and sown as soon as the pericarps turn grayish-brown. Timing is critical, however, and seed collected only 1 week later should be treated with sulfuric acid to allow water to penetrate to the embryo to enhance germination, regardless of whether fall or spring sowing is planned (Vanstone, 1978). White oak should be sown only in the fall because it

germinates soon after sowing. The other species can be sown in either the spring or fall, but fall sowing is likely to be most satisfactory for two reasons. First, germination can begin as soon as temperatures in the spring are suitable and is less likely to be affected by dry weather in the spring. Second, depredation pressure is likely to be less in the fall because more food is generally available. Seed may be harder to find by spring, especially if it is covered with soil.

COMPETITION CONTROL

Competition from annual weeds, grasses, woody shrubs and vines, and other trees will need to be controlled for several years, particularly if seeding is done in clearcuts. Good site preparation will probably result in reduced competition for 1 or 2 years. However, oak, basswood, white ash, and sugar maple seedlings initially grow slowly and probably will need help for at least 3-5 years. The benefits of competition control are illustrated by results of a study on the Hardies Creek Timber Harvest Forest in Wisconsin. Direct-seeded northern red oak that received annual weedings for 7 years averaged about 6 feet tall and the unweeded seedlings averaged about 4 feet tall (Scholz, 1964). Competition control beyond that accomplished with site preparation will be difficult where broadcast seeding is used. For areas seeded in rows or spots, it should be no more difficult than if trees were planted.

Considering the foregoing, the prospects for successful direct seedings do not look very good, at least in the near future. Given the high risk of direct seeding, what might be its advantage over planting? One reason sometimes cited is that direct seeding costs less. Seeding takes less time than planting, particularly if broadcast seeding is feasible. Comparative costs with planting will probably be highly variable. However, when the costs of site preparation, rodent and competition control, and the risk are considered, I suspect any cost advantage for direct seeding is more imaginary than real. Another reason often advanced in favor of direct seeding over planting is that the trees will be more vigorous because they develop in place and grow with root systems not mutilated by lifting and the planting operation; thus, they are less subject to disease and windthrow. However, I could find no hard evidence that proved this.

Although there have been some successful direct seedings of hardwoods, there have been more failures. Until much more information is available to guide direct seeding, it is probably much more prudent to plant where natural regeneration cannot be depended on. Nevertheless, if direct seeding appears to be the only way, the following suggestions are offered:

1. Use quality seed with a known germinative capacity.
2. Determine the sowing rate based on the germinative capacity.
3. Evaluate the probable depredation and control if possible.
4. Prepare the site to reduce competition and destroy seed predator habitat.
5. Sow seed in fall as soon after natural seedfall as possible using a method that will cover seed with soil.
6. Control competition as needed.

Table 1. Seed storage requirements for selected hardwoods

Species	Storage conditions	Length of storage	Viability loss
		years	
Basswood [1/]	Dry at 40° F	2+	No data
White ash [1/]	7-10 percent moisture content at 40° F in sealed containers	7	None
Sugar maple [2/]	10 percent moisture content at 40° F in sealed containers	4.5	Slight
Northern red oak [3/]	30-35 percent moisture content at 35° F in polyethylene bags	2.5	Some
White oak	Storage not recommended		

[1/] U.S. Department of Agriculture, Forest Service, 1974.
[2/] Yawney and Carl, 1974.
[3/] Bonner, 1973.

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IDENTIFYING AND CONTROLLING ANIMAL DAMAGE TO HARDWOODS

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INTRODUCTION

Recognizing plant damage caused by specific vertebrate species is an exercise in deductive reasoning. Even when there are obvious, clearly identifiable signs present (such as hoof prints, droppings, etc.) it is best to conduct a thorough investigation, collect all possible clues, then reason through to a conclusion.

Damage to hardwoods will be caused either by birds, mammals or a combination. Reptiles and amphibians are essentially incapable of damaging woody plants larger than seedlings.

Vertebrates damaging woody plants is a normal function of animal/habitat relationships. This natural phenomenon becomes defined as a problem only when man assigns a higher value--economic or aesthetic to the plant than to the animal. After all, habitat is composed of the elements of food, water, cover and space and if an animal is to utilize its habitat to best advantage some plant materials must bear the burden of damage. This is most easily appreciated relative to herbivores. But, there is a parallel even with some omnnivores and carnivores (e.g. dens, woodpecker drumming trees, black bear scratching posts, etc.).

IDENTIFICATION OF DAMAGE

The upper midwest is home to nearly 600 species of terrestrial vertebrates. Approximately 1/10 of these are capable of damaging woody plants to the degree it could be classified as a problem. It is not possible to address this situation species by species. Discussions will be confined to the major vertebrate groups--birds and mammals.

Birds

Bird damage to hardwoods will, in the majority of instances, be attributable to primary excavators--woodpeckers. However, jays, crows (to a minor degree) and grosbeaks may consume portions of mast, berry and seed crops from desirable hardwoods such as oaks, cherry and maples (Martin et al., 1961). These activities are normally not of economic significance.

Woodpecker damage is easily recognized by nearly everyone who has hiked through a woodlot. Feeding excavations made by the pileated woodpecker (Dryocopus pileatus) are the most impressive because of their size (often 4-5 inches wide and 12-18 inches long) and their characteristic rectangular shape. No other woodpecker in the upper midwest excavates in this fashion. Ants, especially carpenter ants, constitute over one-half of the animal

material consumed. Larvae of wood-boring beetles also form a high percentage of the diet.

Common flickers (Colaptes auratus) also feed on carpenter ants, but their excavations are not nearly so large as those of the pileated, and flicker borings are frequently oval or at least not neatly rectangular. Tree damage by flickers is not common since nearly one-half of the animal food consumed is found on the ground. Ants, ground beetles, grasshoppers, crickets and cockroaches are major food items.

Contrary to common belief, the red-headed woodpecker (Melanerpes erythrocephalus) does little damage to trees. Like the flicker it obtains half or more of its food on the ground, feeding extensively on beetles, ants, termites and grasshoppers. Only a very limited quantity of wood-boring beetle larvae are taken.

One member of the woodpecker group which frequently damages hardwood is the yellow-bellied sapsucker (Sphyrapicus varius). Sapsucker damage is easily recognized. It usually appears as a rectangular patch of small holes (1/8 to 1/4" in diameter) drilled through the bark. The holes within the patch are neatly arranged in closely spaced rows and columns. Occasionally this damage patch may appear as a "belt"--one or more rows of borings which completely encircle the trunk or branch. Sapsuckers, as the name implies, feed on tree sap and wood from several species of trees. Mountain ash, birch, fir and pine are common targets in the upper Midwest. Sapsuckers also consume wood-boring beetles (larvae and adults), ants, spiders, katydid eggs and several other insects.

Downy (Dendrocopos pubescens) and hairy (Dendrocopos villosus) woodpeckers are common throughout the northern hardwood area. These birds are very similar in appearance (hairy is the larger) and food habits. They feed primarily on wood-boring beetle larvae, moths, ants, aphids and scale insects. Less than 30% of the diet of these birds is plant material. This is in contrast to other woodpeckers where plant material (usually fruits or mast) may form 91% during certain seasons (Martin et al., 1961).

The red-bellied woodpecker (Centurus carolinus) is common throughout the Eastern and Midwest hardwood areas. As with the red-headed woodpecker the red-bellied does a relatively low proportion of feeding by boring into trees. Over 60% of its preferred food items are acorns and various tree or vine fruits. It does feed on larvae of some wood-boring beetles and occasionally on small vertebrates such as tree frogs.

Woodpeckers of all types may cause damage to merchantable timber by excavating nest cavities in hard snags. The factors determining the suitability of a hard snag for a nest cavity vary considerably; however, the tree species is not usually as important as dbh, branching pattern, density of wood, location of snag with stand, or snag height (Kitts, 1981; Evans and Conner, 1979; Thomas, 1979).

Mammals

The largest portion of mammal damage to hardwoods undoubtedly occurs as the

result of feeding activity, either the result of direct removal of stem and leaf tissue as food items or indirectly through consumption of mast or fruits. However, where high value trees are cultured (e.g. black walnut) considerable economic loss may develop due to breeding behavior displays. These activities are associated with the ungulates--members of the deer family here in the upper Midwest.

Damage associated with feeding activity of ungulates frequently can be distinguished from that of rodents and lagomorphs (rabbits and hares). Ungulates do not possess maxillary incisors while rodents possess two and lagomorphs have four. Lack of the maxillary incisors creates a torn, shredded edge to the remaining ends of stems and branches on which ungulates have fed. Lagomorphs and rodents leave these materials with a cleanly cut appearance. Lagomorphs, because of rather wide teeth and the orientation of the body to plant while feeding will often leave the end of the attached stem with a cut angle of approximately 45°. This angle is usually less than 45° for rodent cuts, except perhaps for beaver (Castor canadensis), porcupine (Erethizon dorsatum), and woodchuck (Marmota monax).

Debarking and girdling of young trees (to dbh of approximately 4") is generally caused by voles from any of three species (Microtus sp., Clethrionomys sp., or Pitymys sp.). These small brown/gray rodents are common in open forests, forest clearings, along woodlot edges or marshy meadows. Extent of damage varies with the vole population density which often peaks at 4-6 year intervals. Vole damage at any stage of the population cycle tends to be most extensive during winters with persistent snow cover. Damage to individual trees is confined to that portion below the snow line and most often to the 3-4 inches of trunk immediately above the ground level. These animals can be especially troublesome in recently established tree farms, shelterbelts, or reforested areas.

Debarking activities on maple (Acer sp.) concentrated on the branches and upper trunk is often the result of Eastern gray squirrel (Sciuris carolinensis) feeding and displacement activity. This is a phenomenon which usually begins in late winter and continues into spring. Bark stripping often subsides when elms and oaks begin to flower.

The plains pocket gopher (Geomys bursarius) and to some extent the northern pocket gopher (Thomomys talpoides) present challenges to anyone wishing to establish tree farms or shelterbelts. The presence of these fossorial rodents is recognized by the appearance of soil mounds approximately one gallon in volume. Along the perimeter of a freshly created mound will be a circular or horseshoe shaped depression marking the burrow entrance. This mound with depression is characteristic only of pocket gophers.

CONTROLLING DAMAGE

In our modern society we persist in the notion that science and technology can provide us with solutions to all of our problems. In some situations and given certain conditions wildlife scientists and managers can seemingly perform wonders. Yet, in other very similar situations we are constantly frustrated in our attempts to accomplish a seemingly simple task. Trained biologists, be they foresters or wildlife scientists, understand the enormous

complexity of managing renewable natural resources. Those of us who culture these resources in an agricultural setting, whether the resource is black walnuts or ring-neck pheasants become lulled into a false sense of security by the unnaturally simple environment we have temporarily created. Animal damage problems in these settings are good reminders to us that we are not yet in complete control. For every change in the natural system there is a price to be paid--the more closely we work with the system the lower will be our cost.

Birds

All birds except the European starling (Sturvus vulgaris), the house sparrow (Passer domesticus), the rock dove (Columba livia) and the monk parakeet (Myiopsitta monachuse) are protected species. Protection is accorded either through the United States Fish and Wildlife Service or through the various state resource management agencies. Thus, any attempt at damage control directed toward elmination, capture or harassment of birds will require special permits and/or close coordination with wildlife biologists and enforcement personnel of these agencies.

In the majority of instances, direct control of birds is either ineffective or improper. This is especially true of woodpeckers (with the possible exception of sapsuckers). Woodpecker damage to trees is an indication of a flaw in tree culture technique. If the trees are healthy woodpeckers will not damage them since woodpeckers are only interested in insect infested, dead or dying trees. Look to correcting your tree culture technique or timber stand improvement practices to correct the situation.

Mammals

All 50 states have laws regulating the use of poisons to control quadrapeds. These laws vary in complexity from state to state. In addition, many mammals, including several non-game species are considered protected and may not be controlled without state or federal (endangered or threatened species) permits. Any person wishing to control problem mammals, whether on private or public land, should first consult with the proper state and federal authorities.

General control practices are summarized in Table 1. Specific techniques will vary by area.

SUMMARY

Control of problem wildlife in hardwood stands is a challenge to management skills of the wildlife scientist. We are constantly reminded that the success we experience is perhaps more a reward for our artistry in application than for our science in understanding.

Bird control activities usually require special permits--either federal or state. Damage from woodpeckers is the result of a problem, not the cause--check tree culture practices.

Most mammal associated damage results from feeding situations. Three basic approaches to control are exclusion, repellents and population reduction.

Exclusion is only practical for sensitive animals or on small areas. Repellents are at best only short-term solutions. They are quite limited in potential and highly variable in results. Population reduction is usually most effective if conducted during the fall (hunting season for game animals) or winter when the target animals are most susceptible and before the succeeding reproductive period begins.

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Table 1. Summary of Problem Mammal Control Practices

Animal	Damage	Control
Deer	feeding/buck rub bud/twig removal and bark damage	Exclude - Deer-proof fence, electric fence. Repellent - Odor and taste repellents applied--usually late fall--to dormant plants. Scarecrows occasionally work--human odor may help. Herd Reduction - Check with DNR.
Lagomorph	feeding twig removal and debarking	Exclude - Wire mesh fence staked tight to ground 18" high or as necessary to exclude. Individual tree wraps for high value trees. Repellent - Odor and taste repellent applied in late fall to dormant plants. Scarecrows of limited value. Population Reduction - Reduce/remove breeding habitat. Increase harvest during hunting season. Trap and remove during winter--check with DNR.
Rodents	feeding/displacement bud and twig removal, and bark stripping	Exclude - Voles, individual tree wrap for high value trees. Cultivate between rows or mow vegetation between rows late in fall. Squirrels, as above. Pocket gophers, not practical. Repellents - Voles, apply to base of dormant trees in fall--not really practical. Squirrels, not practical. Pocket gophers, not practical. Population Reduction - Voles, rodenticides used in bait stations --check label for amount. Erect nest boxes for kestrels, screech owls, barn owls. Squirrels, NO rodenticides. Increase fall hunting harvest. Trap and removal in winter and early spring--check with DNR. Pocket gopher, Subsurface application of rodenticide with burrow-builder--Check label for correct amount--most effective if done in fall.

CONFERENCE SUMMARY AND THE NEXT STEP

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Conference Summary

The Conference was opened by cochairman Harold Scholten, Professor and Extension Forester, College of Forestry, University of Minnesota. Richard A. Skok, Dean, College of Forestry, University of Minnesota, then delivered a welcome and introductory comments.

The technical program opened with an overview moderated by Carl Vogt, Extension Specialist, College of Forestry, University of Minnesota. Regional characteristics and future opportunities were presented. Ted Curtin, Extension Forester, University of Illinois, stated that since Illinois is such a long state from north to south, it includes many different species and forest types. It has most of its nonindustrial private forests in the prairie area and its forests received a substantial amount of land abuse. Bill Ritter, Regional Forester with the Iowa State Conservation Commission, then emphasized that during the past 25 years Iowa has lost approximately 40 percent of its commercial forest land. A substantial amount of the remaining commercial forest land is in the northeastern part of the state. Ken Anderson, Regional Forester with the Minnesota Department of Natural Resources, stated that Minnesota has between 1½ and 2½ million acres of central hardwoods comprising approximately 15 percent of the state's commercial forests and accounting for approximately 20 percent of the state's timber removals. Adrian Hagen, with the Wiscosnin Department of Natural Resources, summarized that while Wisconsin is approximately 40 percent forested in land area, close to 60 percent of this forest is in private ownership. He added that much of the oak forests had been moving toward less desirable mixed hardwoods, and that in bottomland hardwoods, less disturbance occurs by fire and more by cutting. Currently, much of the forest reproduces by natural regeneration with much more planting needed.

The section on Silvics and Physiology was moderated by Rod Jacobs, State and Private Forestry, U.S. Forest Service, St. Paul, Minnesota. Bob Farmer, Professor, School of Forestry, Lakehead University, Ontario, presented a paper entitled "Seedling Physiology and Growth." He explained the concept of forest regeneration in terms of relative growth rates, with interest being the rate of return on the initial planting investment. He then discussed unit leaf rate of assimilation and leaf area ratio relative to net assimilation rates, and elaborated on population biology concepts and environmental control. All these factors should be considered when looking at physiological influences on hardwood regeneration and growth. He further emphasized that root/shoot ratios should be an important consideration, and all these factors should be analyzed with the objectives of obtaining vigorous planting stock and determining optimal planting times. Questions and discussion followed and were coordinated by Frank Irving, Professor, College of Forestry, University of Minnesota.

The next section was on Natural Regeneration, and also was moderated by Rod Jacobs. Paul Johnson, North Central Forest Experiment Station, U.S. Forest Service, Columbia, Missouri, presented a paper entitled "Upland Hardwoods." Paul divided his discussion into three upland hardwood types: sugar maple-basswood, oak in both zeric and mesic sites, and black cherry-hickory. He stated that sugar maple-basswood grows on the better sites and reproduces aggressively with the exception of poor basswood seed germination. Seedling stock in this type is easily killed by ground fires. He added that selection might be used to favor basswood. Relative to oak on mesic sites, northern red oak forms stump sprouts. He emphasized that if clearcutting is used, advanced reproduction must be in place. All oak reproduction on mesic sites has relatively low survival rates. On xeric sites, reproduction survives much better. If stump sprouts are used for reproduction, they should be thinned to only one stem per stump. If the shelterwood reproduction method is used, only 60 percent of the canopy should be retained. In the black cherry-hickory type, he stated that conversion is difficult.

Gene Garrett, Professor, School of Forestry, Fisheries and wildlife, University of Missouri, then presented a paper entitled, "Bottomland Hardwoods." He emphasized that in bottomland hardwoods, elm and green ash tend to be prominent with red and silver maple and many other species also present. Cottonwood and willow also may be important species among bottomland hardwoods, with cottonwood being favored when the two grow together on the same site. He stated that sprouting ability and fire resistance are important factors to consider in regeneration of bottomland types. Other important considerations include water holding capacity of the soil and the amount of herbaceous material; both which affect the quantity and type of regeneration. Generally, with the opening of the canopy, ground herbaceous material increases and the number of seedlings per acre decreases. If clearcutting is used, red and silver maple may become the predominant species. Major environmental hazards in the bottomland hardwoods include water submersion during flooding and fire effects. Joe Deden, Manager, Tuohy Forest Products, Chatfield, Minnesota, then coordinated questions and discussion.

The next session addressed Artificial Regeneration and also was moderated by Rod Jacobs. Paul Forward, J. W. Toumey Nursery, Ottawa National Forest, U.S. Forest Service, Watersmeet, Michigan, presented the next paper entitled "Production and Handling of Planting Stock." He emphasized that shoot/root ratios, seedling water potential, and seedling vigor are important considerations in selecting planting stock. Management practices should be directed toward maintenance of soil quality in the seed beds. Growth promoting chemicals and top pruning may be useful, and herbicides can provide an effective management tool. Fall or early spring digging during the dormant period should be practiced. Soil should not be frozen but should be dry, and relative humidity should be low. If storage of seedlings is necessary, cool temperatures are important, and air circulation is critical. While container-grown stock holds potential, presently only a small percentage of container-grown seedlings are hardwoods. If storage of container-grown stock is necessary, wind should be reduced or eliminated in the storage area. Questions and discussion were coordinated by Neil Broadwater, County Extension Director, Winona County, Minnesota.

The next paper was presented by Paul Johnson, State and Private Forestry, U.S. Forest Service, St. Paul, Minnesota, and Ed Hays, Minnesota Department of Natural Resources, and was entitled "Matching Species to Site." Site characteristics were emphasized as being important in matching species to site, including topography, soil and climate. Indicator plants also were discussed as related to site quality. Site indices are helpful in making decisions on conversion relative to specific types best supported on given sites. Questions and discussion were coordinated by Terry Helbig, District Forester, Minnesota Department of Natural Resources.

The Conference reconvened on March 3 with the first paper entitled "Herbicides" presented by Harvey Holt, Professor, Department of Forestry and Natural Resources, Purdue University. He defined categories of plants and categories of herbicides relative to their interactions. He then elaborated on application techniques, and finally illustrated situations when herbicides could be effectively used in hardwood regeneration. Questions and discussion were coordinated by Scott Reed, Extension Forester, College of Forestry, University of Minnesota.

The next paper entitled "Open Field Planting" was presented by Ed Godel, Wisconsin Department of Natural Resources. He discussed both site preparation and release in open field situations utilizing techniques such as plowing and herbicides. He also discussed problems created by factors such as hilly terrain and soil types, and emphasized that soil type maps may not identify micro-environmental situations relative to planting.

The next paper entitled "Interplanting" was presented by Paul Johnson, North Central Forest Experiment Station, U.S. Forest Service, Columbia, Missouri. He emphasized that the following questions should be answered relative to interplanting:

1. Is the natural regeneration inadequate?
2. Is natural regeneration feasible?
3. Is the site adequate?
4. When should interplanting be done?
5. What species should be interplanted?
6. What density should be interplanted?

He added that physical quality of planting stock is critical, and further elaborated on modifications of interplanting including under-planting with subsequent release. Questions and discussion were coordinated by Bruce Brown, Professor, College of Forestry, University of Minnesota.

The next presentation entitled "Direct Seeding" was given by Ivan Sander, North Central Forest Experiment Station, U.S. Forest Service, Columbia, Missouri. He emphasized that research using direct seeding has yielded mixed results with hope in some situations. Important considerations should include seed selection and quantity, seed treatment, and seed storage. Subsequent considerations should include site preparation and protection, seeding methods, and site release.

The final presentation entitled "Identifying and Controlling Animal Damage to Hardwoods" was given by Jim Kitts, Extension Specialist, Wildlife and Fisheries, University of Minnesota. He emphasized animal damage control considerations including protection of both regeneration and wildlife. He further discussed specific types of animal damage, and emphasized that alteration of habitat can provide an effective control mechanism. Questions and discussion were handled by Patrick Weicherding, Assistant Extension Forester, College of Forestry, University of Minnesota.

Next Step

The next step in hardwood regeneration is up to field managers and associated administration. They must implement effective practices. During the past several decades, forest managers have increasingly followed the model of agronomists in applying intensive techniques which can be both biologically and economically feasible in forest regeneration. These include practices in nursery management to provide vigorous seedlings and methods in site preparation.

Information flow between field managers and researchers needs to be increased. Field managers need to identify important field problems requiring research, and researchers need to provide information back to field managers. Certainly more information is needed in regeneration of both bottomland and upland hardwoods, including planting and stocking, site preparation, release, and cutting methods.

Students in forestry curricula throughout the United States should receive more exposure to hardwood regeneration problems. Subsequently, continuing education programs in hardwood regeneration for field managers should be increased.

Finally, it is critical that field managers become involved in policy discussions to provide administrators the necessary technical input for policy decision making relative to field prescriptions.

Progress is being made in all these areas. We must continue with even more enthusiasm.